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Preface

The present working report titled “Approach to the Sustainable Forestry of Indigenous Tree Species in Northeast Thailand“ is organized to show the fruits of the initial 5 year phase of joint research project on “Development of techniques for nurturing beneficial indigenous tree species and combined management of agriculture and forestry in the northeast of Thailand, tropical monsoon regions” by the collaboration between Royal Forest Department (RFD) and Japan International Research Center for Agricultural Science (JIRCAS) since 2006.

Thailand once was well known as the Country of Forest. The rich forest covered more than half of nation’s territory until early 1960’s and supported livelihood of Thai nation by the mutual combination with agriculture and fishery, and nursed rich culture as well. This country, however, has experienced quite rapid deforestation down to less than 30% at the end of the 20th century due to the drastic socio-economical change. This loss in the northeast region was the most obvious among all regions of Thailand, in particular.

Thai government had paid great effort to recover such critical loss of nature and promoted planting of fast growing tree species as the fast aid and successes apparently. The fast growing species plantation, however, offers only pulp or fuel wood. The recovery of high ecological service that rich forest used to produce can’t be expected. Royal Forest Department therefore has launched on the research to develop the sound technique to convert plantation of fast growing tree species to endogenous high economic valued species stand since late 1980’s as the following step to re-install rich forest ecosystem to the northeast. Introducing to plant national symbolic tree species, Teak, to the northeast was also one of the challenges to root firm source of supporting livelihood with rich forest ecosystem to the region. Our collaborative research project has been piling up various useful results upon the accumulation of experience and findings from those previous trials. We pay deep respects to the initiators of those trials.

We JIRCAS are honestly proud on our collaboration which has been woven with Thai forest scientists both of RFD and the other institutions, forest officers as well as plantation owners. Our challenge toward the great goal has just launched on. We expect further keen collaboration over another five years and farer for obtaining highly user-friendly results and the contribution to society with smooth use of the knowledge. We hope the Working report can contribute to the development of emerging small scaled private forestry in Thailand.

Ryuichi Tabuchi

Director of Forestry Division

JIRCAS

Contents

Growth performance of indigenous tree species under uneven-aged forest management in Northeast Thailand

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Abstract

For the purpose of conversion of a fast-growing tree plantation into indigenous tree forest in monsoon Asia, growth performances of indigenous tree species under various light conditions were examined. An uneven-aged (two-aged) system in which indigenous trees were underplanted in a fast-growing tree plantation was applied for this conversion on a trial basis in the Sakaerat Silvicultural Research Station, Northeast Thailand. Experimental plots were established from 1987 to 2009 and survival rates and growth in terms of the height of indigenous tree seedlings were examined under various forestry operations (free selection thinning, stripe thinning, group selection thinning in two-aged system, and even-aged system). The results suggest that *Dipterocarpus alatus*, *Hopea odorata*, and *Dalbergia conchinchinensis* could be planted in an open site without a two-aged system. It was recommended that other dipterocarp species (*D. turbinatus*, *H. ferrea*, and *Shorea henryana*) be planted under a two-aged system. Since *H. odorata* and *Xylia xylocarpa* var. *kerrii* adapted to various light conditions, they could be applied to both even- and uneven-aged systems. Group selection thinning was recommended in terms of both the growth performance of the seedlings and the efficiency for logging, when a two-aged system was selected.

Keywords: growth of seedling, light condition, nurse tree, survival rate, thinning

Introduction

Indigenous tree species are expected to provide high-value timber and contribute to the conservation of biodiversity as well as local cultures against the background of decrease and degradation of forest resources around the world (FAO 2010). However, silvicultural techniques for indigenous tree species have not been improved compared with those of exotic fast-growing trees owing to limited experience and a lack of information about site suitability and growth performance in a given environment (Montaginini and Jordan 2005).

One of the negative factors that could bother afforestation of indigenous tree species is high mortality of seedlings, such as that caused by strong sunlight in an open site (Norisada et al. 2005; Hattori et al. 2009). In order to deal with this, uneven-aged forest management (UAFM) has been examined in tropical areas (Kamo et al. 2009; Norisada et al. 2005; Sakai et al. 2009). Advanced studies on uneven-aged forest called "enrichment planting" have been conducted in Malaysia (Chan et al. 2008). Most of them have followed a "two-aged system" in which advanced stands are thinned in a given pattern (random selection, stripe, and group selection) for succeeding stands. In this system, residual canopy trees (nurse trees) are expected to mitigate the effects of strong sunlight on young seedlings. Fire in the dry season is one of the main factors that hamper the establishment of forest plantations in the monsoon climate in Thailand (ITTO 2006). Planting fast-growing trees in large degraded areas of land was significantly effective for containing fires because they covered the ground quickly and suppressed grasses, which often cause fires in the dry season. Thus, planting indigenous trees after the establishment of fast-growing tree plantations could be a reasonable approach to introducing indigenous trees in large areas of degraded land.

The aims of this paper are to review previous studies at the Sakaerat Silvicultural Research Station and to learn lessons on silvicultural techniques from these results. The authors will suggest appropriate species combination and

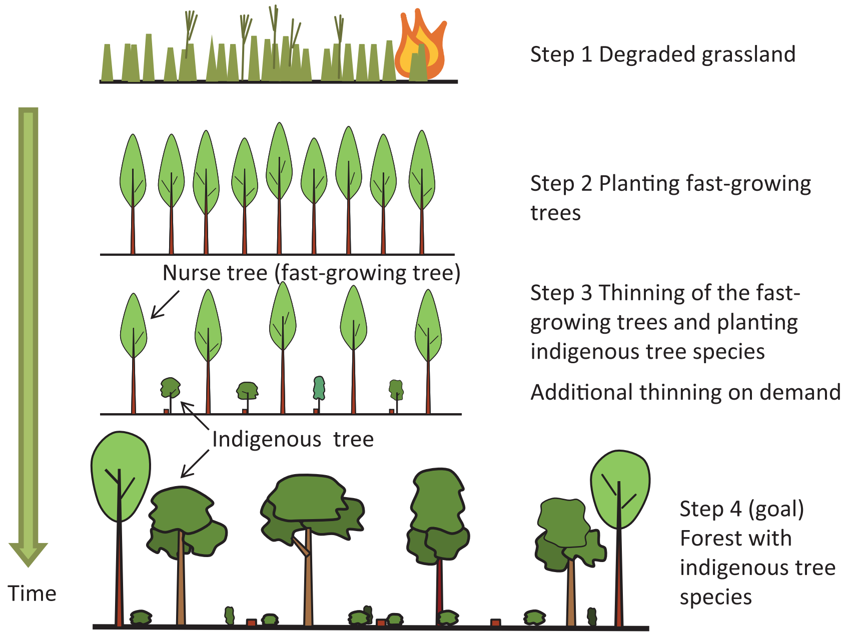

Fig. 1. A schematic diagram illustrating the course starting from degraded land to a forest composed of indigenous tree species.

thinning system suitable for two-aged system by screening the survivorship and growth of indigenous tree species. We will also suggest proper forestry system (normal even-aged system or two-aged system) for proper indigenous tree species by reviewing the results.

Study site

A series of studies were conducted at Sakaerat Silvicultural Research Station, Nakhon Ratchasima Province, in Northeast Thailand. The mean annual air temperature was 25.6 °C and the mean annual rainfall was 1395 mm according to meteorological data collected at the administrative office of the station over the last 10 years (1999 to 2009). This area has a monsoon climate with highly seasonal rainfall and a roughly 4-month-long dry period from November to February. The soil is deep loamy acrisol formed on sandstone laid down in the Triassic to Cretaceous periods (Moormann and Rojanasoonthon 1972) and generally contains a small amount of organic matter (Ando and Iwasa 1987). The vicinity of the study site was covered with dry evergreen forest until the 1960s. The forest was then encroached by local people, who converted it into farmland. Although the farmland was cultivated for a couple of decades, most of it was subsequently abandoned and covered with tall grasses such as *Imperata cylindrica* and *Saccharum spontaneum*. The Research and Training in Re-afforestation Project (RTR Project) conducted by Japan International Cooperation Agency (JICA) and the Royal Forest Department (RFD) was initiated in 1982 with the planting of exotic fast-growing tree species over 2300 ha by 1994. The area is currently covered with mature fast-growing tree plantations mainly composed of *Acacia mangium* and *Eucalyptus camaldulensis*.

Scheme of uneven-aged forest management at the Sakaerat Station

Fig. 1 shows a schematic diagram of degraded land converted into a mature forest composed of indigenous tree species via a fast-growing plantation. After the abandonment of cultivation in deforested areas, tall grasses (*Imperata cylindrica* and *Saccharum spontaneum*) cover the land, often inducing fires (Step 1). By planting fast-growing trees, the degraded area is converted into a plantation, reducing the risk of fires (Step 2). It has been proved that *Acacia mangium* is suitable for afforestation around Sakaerat (Ando and Iwasa 1987). Seedlings of indigenous tree species are planted beneath the canopy of plantation or in a gap formed after thinning (Step 3). Additional thinning or harvest logging will be needed on demand. Thereby, a forest composed of indigenous tree species is created (Step 4). It is expected that this forest will provide high biodiversity of plants, animals, and insects. At present (2011), most of the area around Sakaerat Station is categorized as Step 2, while small experimental sites are at Step 3 or 4.

Methods

Experimental plots

A total of five experimental plots for analysis of the two-aged system were established at Sakaerat Station from 1986 to 2009 (Table 1).

Experiment No. 1

This plot was established in 1986 for the purpose of finding appropriate species combinations in a two-aged system (Table 1) (Sakai et al. 2009). *Hopea odorata* (Dipterocarpaceae) was planted beneath 3-year-old

Table 1. A list of the experimental plots for uneven-aged system at the Sakaerat Station

Experimental plot No	Year of setting	Nurse tree species	Stand age at underplanting	Indigenous tree species	Forestry operation	Grade of lightness
1	1986	*Eucalyptus camaldurensis*	3	*Hopea odorata*	no thinning	4
		Acacia auriculiformus	3	*H. odorata*	no thinning	4
		Senna siamea	3	*H. odorata*	no thinning	4
		-	-	*H. odorata*	open site	14
2	1989	*Leucaena leucocephala*	3	*Dipterocarpus alatus, D. turbinatus, H. odorata, Shorea henryana*	no thinning	5
		-	-		open site	15
3	1999	*Acacia mangium*	14	*Dipterocarpus alatus, D. turbinatus, H. odorata, Afzeria xylocarpa, Dalbergia cochinchinensis, Pterocarpus macrocarpus, Xylia xylocarpa* var. *kerrii,* etc.	no thinning	1
		A. mangium	14		stripe, 50%	7
		A. mangium	14		group selection thinning	11
		-	-		open site	16
4	2007	*A. mangium*	23	*H. odorata, H. ferrea, X. xylocarpa* var. *kerrii*	no thinning	3
		A. mangium	23		random selection, 33%	6
		A. mangium	23		random selection, 67%	8
		-	-		group selection thinning	12
5	2009	*A. mangium*	25	*D. alatus, H. odorata, H. ferrea, S. henryana, P. macrocarpus,* etc.	no thinning	2
		A. mangium	25		stripe 50%	9
		A. mangium	25		stripe 67%	10
		A. mangium	25		group selection thinning	13
		-	-		open site	17

plantations of three legume tree species and in an open site with three replications.

Experiment No. 2

Four dipterocarp species were planted beneath a 3-year-old *Leucaena leucocephala* (Leguminosae) plantation in 1989 (Table 1). The identical dipterocarp species were planted with the same arrangement in an open site adjacent to the *L. leucocephala* plantation.

Experiment No. 3

Study plots were composed of stripe thinning plots with a control plot (no thinning), a group selection thinning plot, and an open site plot. Three dipterocarp species and six legume species were planted beneath a 14-year-old *Acacia mangium* plantation in 1999, after applying stripe thinning or group selection thinning (20 m by 36 m in size) in the *A. mangium* plantations.

Experiment No. 4

Two dipterocarp and one legume species were planted beneath a 23-year-old *A. mangium* plantation in order to test their growth performance beneath a mature stand (Sakai et al. 2011) (Table 1). The indigenous trees were underplanted in 2007 after free selection thinning and group selection thinning (50 m by 60 m in size) was applied to the *A. mangium* plantation. Two grades of thinning rate (33% and 67% of basal area) were set for free selection thinning.

Experiment No. 5

Six indigenous tree species were planted in a 25-year-old *A. mangium* plantation after stripe thinning and group selection thinning (Table 1). One-row-cut one-row-left (50% of trees were removed) and two-rows-cut one-row-left (67%) were set for the stripe thinning. The size of group selection thinning was approximately 50 m by 50 m. The identical indigenous species were planted in an unthinned plantation and an open site.

Overview of the results

Survival rate and size of the major indigenous species at 1.5-3 years after planting were summarized for each experimental plot. Relative light intensity on the forest floor (at 1 m above the ground) at planting was estimated in each experimental plot in accordance with the literature or actual observation, and plots were ranked in order of brightness (Table 1).

Among dipterocarp species, survival rates of *D. turbinatus* were low in general, and those of *D. alatus* were low in dark conditions (Fig. 2). Other dipterocarp species exhibited moderate to high survival rates of over 60% in all light conditions. In particular, *H. ferrea* achieved high survival rates in every light condition. Most dipterocarp species showed high survival rates in the intense thinning plots and group selection thinning plots (Fig. 2).

The dipterocarp species tended to be small in dark conditions (beneath unthinned *A. mangium* plantations) and tall in the group selection thinning plots or heavy thinning plots (Fig. 3). The growth in terms of height was limited in the open sites the same as in the low-impact thinning plots (Fig. 3). *H. odorata* exhibited the highest score among the dipterocarp species in a given light condition. *H. ferrea* also tended to be tallest except in the open sites. *D. alatus* remained small in the unthinned or low-impact thinning sites but grew taller than the other dipterocarps in the open

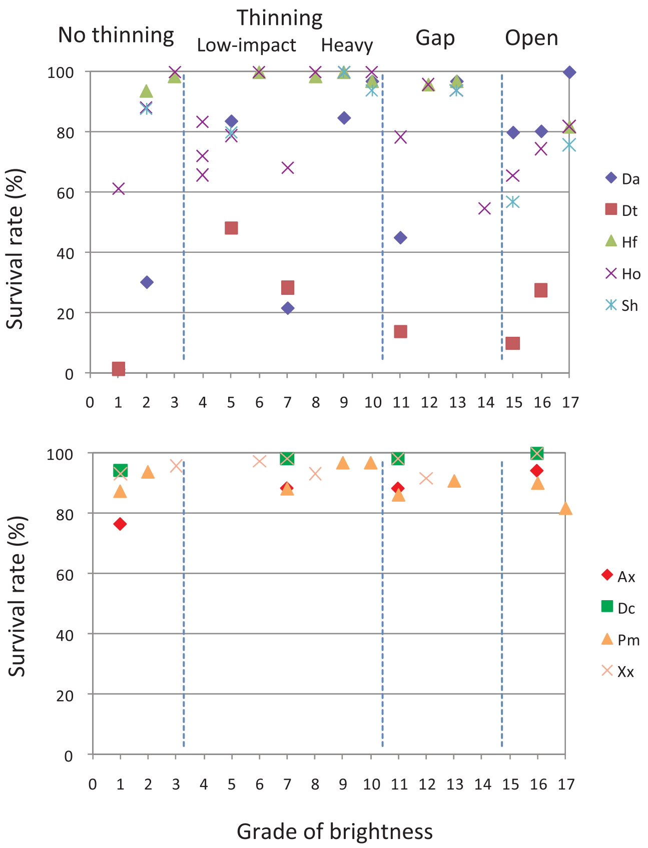

Fig. 2. Initial survival rates of the indigenous tree seedlings in various light conditions in the experimental plots at Sakaerat Station.
Above: Dipterocarpaceae, Below: Legminosae, Da: *Dipterocarpus alatus*, Dt: *D. turbinatus*, Hf: *Hopea ferrea*, Ho: *H. odorata*, Sh: *Shorea henryana*, Ax: *Afzeria xylocarpa*, Dc: *Dalbergia cochinchinensis*, Pm: *Pterocarpus macrocarpus*, Xx: *Xylia xylocarpa* var. *kerrii*

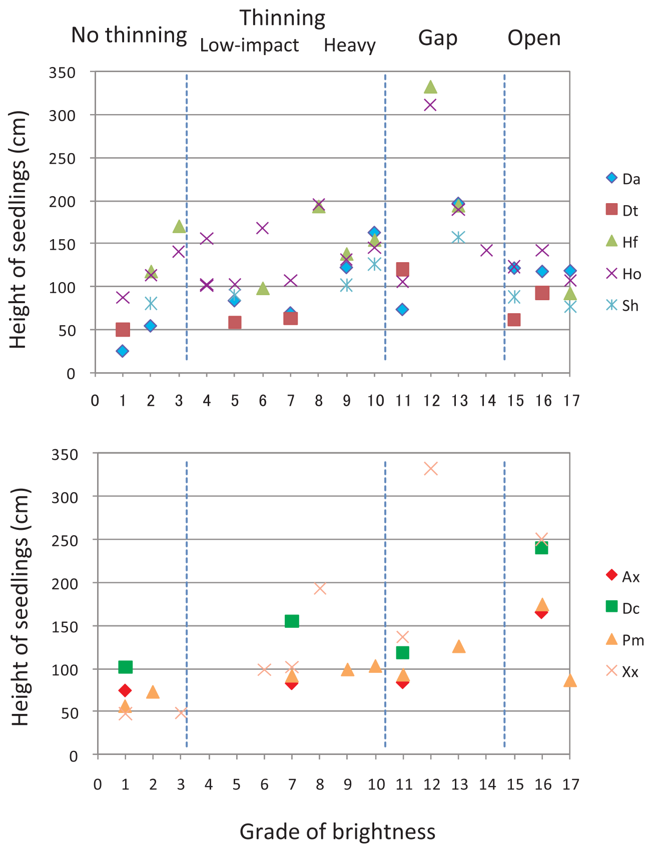

Fig. 3. Initial height of the indigenous tree seedlings in various light condition. Legends are as in Fig. 2.

sites. Meanwhile, the seedlings of *D. turbinatus* and *S. henryana* tended to be small in every light condition.

Legume species showed excellent survival rates of over 80% in every light condition (Fig. 2). All legume species tended to grow as light conditions improved, exhibiting the greatest height in the open sites. In particular, *Xylia xylocarpa* var. *kerrii* and *Dalbrgia conchinchinensis* showed excellent growth in the open sites.

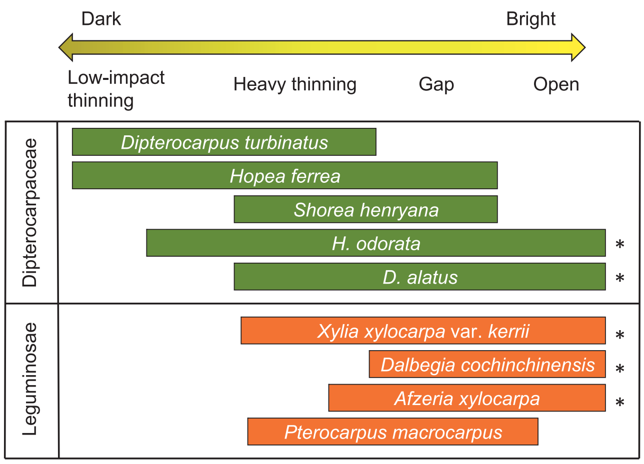

Fig. 4. A schematic diagram indicating suitable forestry operation (light conditions) for each indigenous tree species. The asterisks (*) show tree species possible to plant in an open site.

1. Combination of species

Hopea odorata was the most common species among the indigenous tree species examined at Sakaerat Station, providing a wealth of information on the growth performance of this species. *H. odorata* grew well beneath *Senna siamea* plantations as well as in open sites (Sakai et al. 2009). *H. odorata* also exhibited a high survival rate beneath a *Leucaena leucocephala* plantation, although its growth in terms of height was limited (unpubl. data). Because S. siamea grew slowly, the canopy of *S. siamea* had not closed at the time of underplanting *H. odorata*, providing suitable light conditions for the *H. odorata* seedlings (Sakai et al. 2009). *H. odorata* and other dipterocarp trees could survive and grow under the canopies of *L. leucocephala*, suggesting that this legume tree also provides suitable light conditions, perhaps due to the thin

Table 2. Descriptions of tree species examined at the Sakaerat Station. All species are indigenous to Thailand

Fmily name	Species name	Distribution *	Uses *	Exp. Plot No.
Dipterocarpaceae	*Dipterocarpus alatus*	Indochina, Myanmar, Philipines	construction timber, dammar	2, 3, 5
	D. turbinatus	Indochina	lack of information	2, 3
	Hopea odorata	Indochina, Myanmar, Peninsular Malaysia	timber as “merawan”, dammar	1, 2, 3, 4, 5
	H. ferrea	Indochina, Peninsular Malaysia	timber as “giam”, dammar	4, 5
	Shorea henryana	Southern Indochina, Myanmar, Peninsular Malaysia	construction timber, ship building	2, 5
Leguminosae	*Dalbegia cochinchinensis*	Indochina	furniture, fine arts	3
	Pterocarpus macrocarpus	India, Myanmar, Indochina	construction timber, furniture	3, 5
	Xylia xylocarpa var. *kerrii*	Indochina, Myanmar	construction timber, furniture	3, 4
	Afzeria xylocarpa	Indochina, Myanmar	various woodworks	3

* Arranged by PROSEA (1994; 1998) and Smitinand and Santisuk (1981)

foliage in the canopy (unpubl. data). In contrast, cultivation of *H. odorata* in *A. mangium* or *E. camaldulensis* plantations for a long period without heavy thinning caused irreversible damage to *H. odorata* (Sakai et al. 2009; 2010). In particular, *A. mangium* seems to be unsuitable as a nurse tree owing to its thick foliage. Sakai et al. (2009) found trade-off relationships between basal areas of nurse trees and underplants, suggesting that *H. odorata* would survive and grow in *A. mangium* plantations if thinning was applied at appropriate times.

Our data suggests that *D. alatus* and *H. odorata* could be planted in open sites if the plantation site was carefully tended. Legume trees examined at Sakaerat Station also preferred open sites rather than locations beneath nurse trees (Figs. 2 and 3). However, caution should be taken when putting these findings into practice because these results were obtained in small areas, under well-controlled conditions. Weeding and liana cutting must be practiced three times a year until canopy closure. The planting of several species mixed together is recommended to educe their growth potential and to avoid disease and insect damage (Montagnini and Jordan 2005).

2. Thinning system

Compared with low-impact thinning (thinning rate < 50%), heavy thinning (thinning rate ≧ 50%) tended to have positive effects on the growth of dipterocarp species (Fig. 3). Group selection thinning educed the high performance of dipterocarp species in terms of both survival rate and growth (Fig. 3). Light intensity in the canopy gaps created by group selection thinning was reduced to 60 - 65% of that in the open sites (Sakai et al. 2011), possibly providing suitable light conditions for the indigenous tree seedlings. Although *D. alatus* and *H. odorata* showed excellent growth in the open sites, the survival rates of the seedlings decreased conversely. It was observed that individuals that survived in the open sites grew larger than those in fast-growing tree plantations, compensating the loss of dead individuals (Exp. Plot No. 3, unpubl. data). Lapongan and Kelvin (2009) also reported similar results for dipterocarp species indigenous to Sabah, Malaysia.

It seems that any thinning method is acceptable if the light intensity of the forest floor is kept to approximately 60 -65% of that in open sites. In terms of working efficiency at logging, stripe thinning or group selection thinning seems to be more efficient than free selection thinning because (1) workers could select trees mechanically without expertized skill, and (2) indigenous seedlings would be less damaged at the time of harvest logging of nurse trees. The experiences of this study, however, suggest that stripe thinning in mature *Acacia mangium* plantations was not efficient because large crowns of the nurse trees (approximate 23 m in height) tangled with each other at the time of logging, severely decreasing the working efficiency (Exp. Plot No. 5). We assume that the stripe thinning ought to be applied when the plantation (*A. mangium*) is young (probably < 10 to 15 years). In contrast, early thinning could not maintain good light conditions over long time because the canopy closed quickly in young plantations (Exp. Plot No. 1 and 3). In this case, additional thinning or harvest logging will be needed in the near future (Sakai et al. 2009). It is assumed that group selection thinning is the most efficient system for logging since workers do not need to consider the felling direction of logging trees, especially at Step 3 (Fig. 1). Hence, group selection thinning would be a reasonable system for the conversion from fast-growing tree plantations into indigenous tree forests, in terms of not only growth and health of the indigenous seedlings but also the working efficiency at the time of logging.

Conclusions

Our studies demonstrated that some indigenous tree species such as *Dipterocarpus alatus*, *Hopea odorata*, *Dalbergia conchinchinensis*, and other legume species, which all produce high-quality timber, could grow successfully in open sites without relying on a two-aged system (Fig. 4). However, this is conditional on weed cutting and liana cutting across the whole area in question, as well as controlling the risk of fires in the initial stage. *Dipterocarpus turbinatus*, *Hopea ferrea*, and *Shorea henryana* would be suitable to grow in a two-aged system. Owing to their poor growth performance, these species will be applicable to forest rehabilitation rather than timber production. Long-term planning and practice across every step of forest conversion (cf. Fig. 1) and meticulous maintenance of plantations will be needed. Because *H. odorata* and *Xylia xylocarpa* var. *kerrii* can adapt to various light conditions (e.g. Sakai et al. 2011), they can be applicable to both even-aged and uneven-aged stands. It is worthy of attention for foresters that mixed-species stands result in high growth performance, providing different products at different times (Montagnini and Jordan 2005; Sakai et al. 2009).

Our results suggest that relatively slow-growing trees and/or thin foliage trees (e.g. *S. siamea*, *L. leucocephala*) are suitable as nurse trees in the two-aged system. According to our experience, it is recommended to plant indigenous tree species when the nurse trees are young (3-5 years old), and to harvest all or half of the nurse trees at 5-8 years old, since the indigenous tree seedlings are established by then. The final harvest of the nurse trees should be undertaken within few years, avoiding the long-term vertical overlap of the nurse trees and indigenous trees. At the time of harvesting, the nurse trees would reach a suitable size not only for pulp processing but also for fuel wood and/or charcoal. As Sakai et al. (2009) pointed out, fast-growing trees such as *E. camaldulensis* and *A. mangium* could be used for nurse trees, if strong or frequent thinning was carried out. In the case of utilizing large timber of *A. mangium* or for the purpose of rehabilitation or restoration of natural forests, group selection thinning (the size of the gap is set to double the height of surrounding nurse trees) is recommended in terms of both growth performance of indigenous trees and working efficiency.

Acknowledgements

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A modeling approach to sustainable forest management: "Virtual Forest" predicts forest growth and canopy structure

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Abstract

A modeling approach is essential for quantifying the heterogeneity and complexity of forest composition and dynamics, both spatially and temporally. Simulation models also facilitate the development of guidelines for forest management. To aid in the introduction of indigenous trees on degraded land after the establishment of fast growing tree plantations, we developed models to quantify thinning effects on the growth of canopy trees (*Acacia mangium*) and understory trees (*Hopea odorata, H. ferrea, Xylia xylocarpa* var. *kerrii*) in two -storied plantation forests at the Sakaerat Silvicultural Research Station, Thailand. These models were validated partly using data collected during the monitoring of the 23-year-old *Acacia mangium* plantation. By employing these models, adequate forest management plans can be selected heuristically, prior to any activity. The models were as follows.

(1) A model to simulate the growth of canopy trees in response to thinning practices; this can predict biomass growth and structural development of forests. This model is applicable to plantation forests containing fast growing species.

(2) "Virtual Forest" to evaluate the light environment under the forest canopy. This is a graphical technique, creating a computer generated virtual forest with various tree sizes and structures. The light environment in the study plots was successfully modeled by "Virtual Forest", and validated using hemispherical photographs taken in the plots.

(3) A model to estimate the growth of understory trees. The height growth of understory trees depends mainly on the light environment under the forest canopy, particularly in darker conditions. Adopting a logistic growth curve, height growth patterns of understory trees were effectively modeled, demonstrating seasonal step-wise growth.

Keywords: canopy gap, hemispherical photography, stand structure, thinning, undergrowth

Introduction

A large area of exotic, fast-growing tree species has been established across Southeast Asia over the last half century, and much effort has been put into planting indigenous trees under this forest canopy (Montagnini & Jordan 2005; Sakai et al. 2009). The main fast-growing, short-rotation species used in plantations are in the genera *Eucalyptus* and *Acacia*, and to a lesser extent, *Gmelina* (Montagnini and Jordan 2005). This "two-storied forest management" is expected to provide suitable light conditions for indigenous tree seedlings by shading them in their initial stage of growth (Fujimori 2001).

In Thailand, an experimental two-storied forest plantation was established in 1987 in a Re-afforestation Project initiated by the Japan International Cooperation Agency (JICA) and the Royal Forest Department of Thailand. It was then necessary to develop effective management techniques, to evaluate thinning effects on the growth of canopy trees and to control the light environment so as to promote the growth of understory trees of indigenous species. The objective of the study described herein was to develop several modeling approaches: (1) to simulate the light environment in relation to forest canopy structure; (2) to quantify the growth response of seedlings of indigenous tree species to light conditions on the forest floor; and (3) to predict stand growth with respect to various thinning regimes in a plantation forest.

Material and Methods

1. Study site

The models were developed in order to simulate tree growth and the light environment on the forest floor in a two-storied plantation forest at the Sakaerat Silvicultural Research Station (14°30'19"N, 101°53'28"E, 630m a.s.l.), Nakhon Ratchasima Province, northeast Thailand.

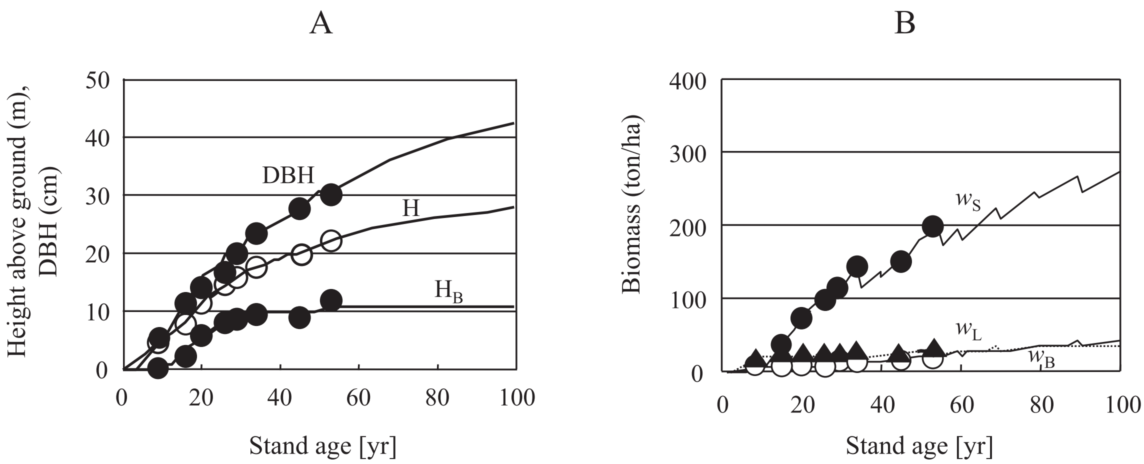

Fig. 1. Simulation of tree size development and biomass growth with different thinning regimes.
A: tree size (D, H, H_B); B: biomass growth of tree organs.
w_S: stem weight; w_L: foliage weight; w_B: branch weight

According to the records for the past 10 years from the nearby meteorological station, the annual mean air temperature and precipitation are 25.6°C and 1,395mm, respectively. This area experiences a monsoon climate with a dry season lasting roughly 4 months, from November to February. The study site is described in detail by Sakai et al. (2011).

This area was covered with dry evergreen forest until the 1950s (Kamo et al. 2002). Most of the forest area was converted to farmland in the 1950s and farmed for a couple of decades, and subsequently abandoned to become covered with tall grass species such as *Imperata cylindrical* and *Saccharum spontaneum*. In 1994, the Re-afforestation Project was initiated by the Japan International Corporation Agency (JICA) and the Royal Forest Department, Thailand (RFD), in order to re-afforest an area of 2,500 ha using exotic fast-growing tree species (Kamo et al. 2002).

2. Experimental design of the study plots and the data used

The details the study plot design are given in Sakai et al. (2011). In 2007, the study plots were established in a 23-year-old plantation forest of *Acacia mangium*, at a spacing of 2m by 3m. The ranges of mean tree heights and DBHs in each plot were 25.2-28.7m, and 21.5-25.9cm, respectively.

In late June 2007, three indigenous tree species (*Hopea odorata* Roxb., *Hopea ferrea* Lanessan and *Xylia xylocarpa* (Roxb.) Taubert var. *kerrii* (Craib & Hutch.)) were planted under the canopy trees at a spacing of 2m by 3m. In order to examine the growth response of the understory trees to the light environment, nine quadrates (18 m by 24 m) under the canopy and one and a canopy gap (50m by 60m) of canopy gap plot that was clear-felled were set up in the *Acacia mangium* plantation in June 2007. In the nine quadrats, the canopy trees were randomly thinned to create four different light environments: i.e. none, one-third or two-thirds of live trees were thinned randomly, and, in addition, there was one canopy gap plot.

The data used to analyze and validate the models were: the understory tree sizes (stem diameter at 30 cm above the ground (D30) and height (H)) and the sky factor (Inoue 1996; Yamamoto 2003), a measure of the light environment under the forest canopy. The sky factor was determined by means of hemispherical photographs.

Results and Discussion

1. Model of canopy tree growth in response to thinning

After the forest canopy has closed in a plantation, tree crowns will retreat upwards from the base of the crown. Provided that an almost constant stand density (number of trees per ha) remains after canopy closure, the mean crown length will stay almost constant so that the height at the crown base increases along with the tree height. However, once the canopy is opened as a result of thinning, the height at the crown base H_B will stay as it is until the canopy closes again. After the canopy closes again, the height of the crown base may move upwards with tree height. Hence, crown length will increase stepwise in association with every thinning operation (Chiba 2006).

The plantation forest growth model was developed on the basis of such processes of crown development in relation to thinning treatments. (Chiba 1990b; Chiba 2006). For typical thinning regimes in plantation forests, tree sizes (averages of tree height H, diameter at breast height D, height at the crown base H_B, crown length CL) in a stand can be predicted by the model (Fig. 1). At the initial planting stage, H_B is almost zero because the canopy has not closed yet. H_B then starts to increase at a stand age of about 10 years when the canopy closes. Subsequently, the crown length ($CL = H - H_B$) shows a gradual increase with repeated thinning treatments over the course of stand development. As shown in Fig. 1A, there was good correspondence between the simulated results and real data for Japanese cedar (sugi: *Cryptomeria japonica*) plantations. By employing a stem form model (Chiba 1990 a), *D* can also be determined for each stand age. Of course, plantations of fast growing trees exhibit much faster canopy closure than sugi plantations. However, since the development of stands subjected to thinning, with respect to tree size, crown structure and canopy closure, is likely to proceed in the same way irrespective of growth rate, it should be possible to apply this model to *Acacia mangium* plantations.

Mean crown length *CL* in a plantation forest can be approximated by a power function involving stand density (Chiba 2006). Employing the allometric relationship between *CL* values and the mean weight of tree organs, the weights of leaves and branches can be estimated from *CL*. In addition, stem weight exhibits a well known allometric relationship, being approximated by D^2H. The biomass development of the plantation forests was simulated on the basis of these relationships, as shown in Fig. 1B. The saw-tooth appearance of the growth pattern for each organ can be ascribed to the thinning treatments. Such modeling approaches could be applied to the plantation forests at the Sakaerat Experimental Station, although a data set including the biomass of fast growing tree species (e.g. *Acacia* and Eucalypts) is needed to parameterize the models mentioned above.

2. "Virtual Forest" for light environment evaluation

It would be useful to be able to examine various forest practices to find the best one without wasting time and resources. A modeling approach is, therefore, essential for managing forests with their heterogeneity, complex tree composition, and spatial and temporal dynamics. The "Virtual Forest" (VF) which can be customized to suit the user's preferences, could be a convenient and practical tool for evaluating the effects of thinning on the light environment in forests with various stand ages, canopy structures, and tree species. Since the VF exists as a computer model, it is possible to test as many thinning regimes as required in order to find the appropriate one to achieve specific goals.

The VF comprises a model tree with a given size: *H*, *D*, *CL* and crown structure. In order to determine the crown structure, the following assumptions were made. The number of branches in a unit length (one meter) is 30. Branch length is determined by a Mitscherlich curve with respect to the distance from the top of the tree:

$$LB(z) = L_{\max} (1 - \exp(- a / L_{\max} z)) \qquad (1)$$

where z is depth from the tree top (m), LB(z) is branch length diverging from the stem at z (m), $L_{\max}$ is maximum branch length (m) and a is a constant (dimensionless). In addition, branch orientation angle could be a significant factor to make crown structure appear natural. After examining the branch orientation angle in relation to adjacent branches, we adopted an angle of 132° (Fig. 2). In the VF, tree locations can be specified: e.g. even, random locations, rows or clusters (Fig. 3).

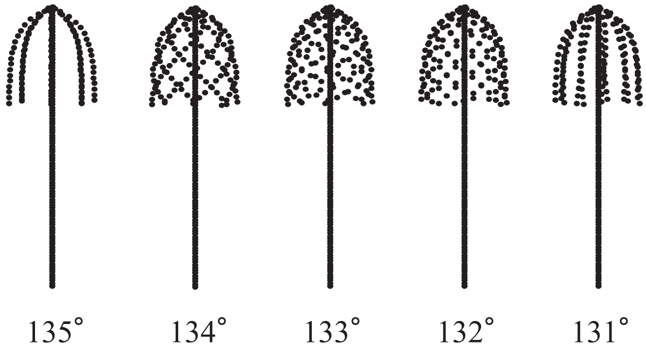

Fig. 2. Spatial distributions of branch apices depending on the angles between adjacent branches of a model tree.
Numbers in the figure are the angles between adjacent branches. An angle of 132° is the best to achieve a natural branch distribution.

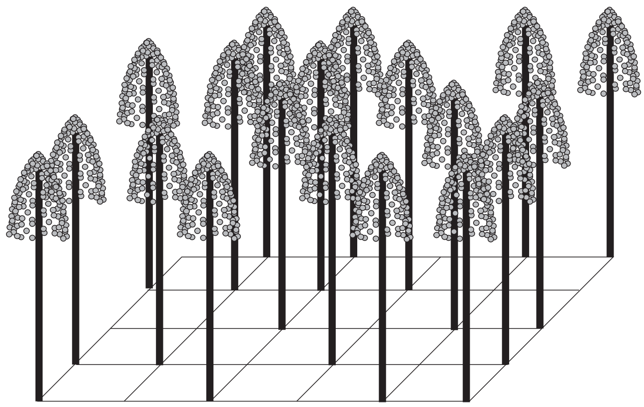

Fig. 3. An example of "Virtual Forest" comprising computer models of canopy trees.
Tree size and location in the forest can be specified.

Since all points in the VF have 3D coordinates, it can be transformed geometrically into a hemispherical view to determine canopy openness. Using the data for tree locations along with hemispherical photographs obtained in the study plots at Sakaerat (Sakai et al. 2011), the simulated canopy openness at several locations was compared with the real data (Fig. 4). These photographs were taken near the canopy gap, so that each photo includes a gap on the left. The lower diagrams in Fig. 4 were derived from the VF, using the actual tree locations in the plot. In this study, the "sky factor" (SF) was used as an indicator of canopy openness and light environment, according to Yamamoto (2003). Comparing the SF values of these actual photos with the simulation, we find that the VF can effectively simulate the light environment under a variety of forest

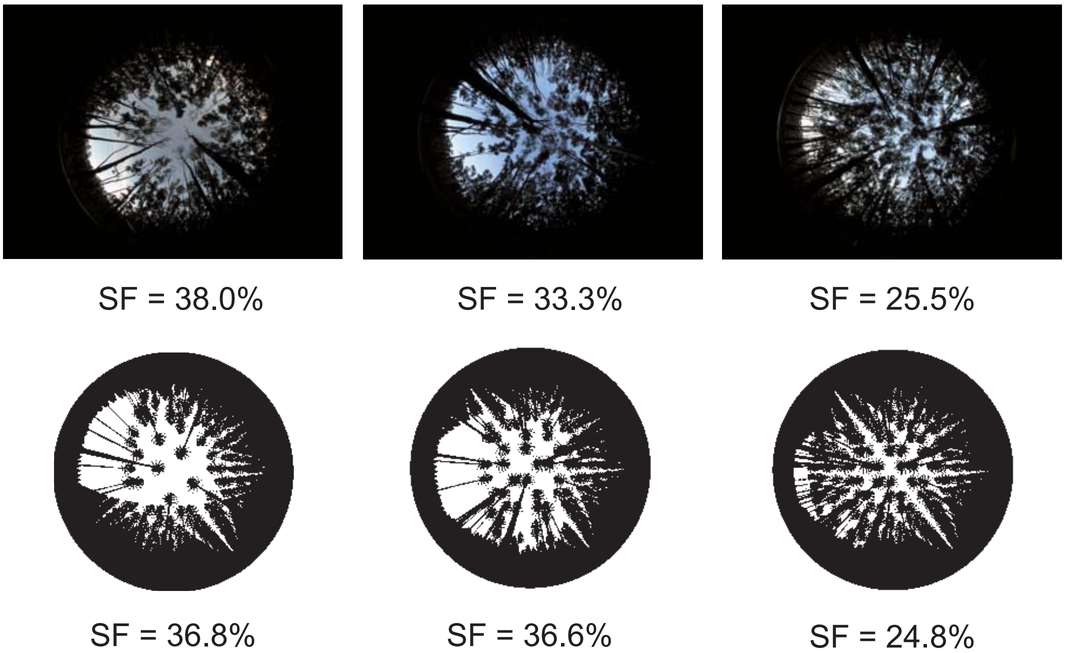

Fig. 4. Examples of hemispherical views of forest canopies simulated on the basis of actual tree locations in an *Acacia mangium* plantation.
The upper figures show the hemispherical photos taken in the plots, and the lower figures show the simulated hemispherical views at the same locations. SF denotes the "sky factor" (see text for detail).

canopies.

3. Height growth of understory seedlings

Understory trees planted in a multi-storied forest are affected by microclimate, including air temperature, light environment, soil moisture and nutrient conditions. Of these factors, the light conditions are likely to be a critical for understory trees, particularly in dark conditions, which strongly affect height growth rate (see Fig. 5). Even in a tropical forests, tree growth exhibits seasonal variation as a result of differences in precipitation and humidity through the year.

Height growth of understory trees at the experimental sites in Sakaerat has been monitored since July 2007. The data exhibit a step-wise pattern of height growth following the dry seasons (Fig. 6). The height growth rate of understory trees was approximated by a simple logistic growth curve incorporating growing period (day of the year):

$$\Delta H(t) = \frac{\Delta H_{max}}{1 + (\Delta H_{max} / \Delta H_0 - 1)\exp(-\lambda t)} \quad (2)$$

where $\Delta H(t)$ is height growth rate at time (day of the year) t, ΔH_{max} is the maximum height growth rate for $\Delta H(t)$, ΔH_0 is initial height growth rate and λ is a growth coefficient. It should be noted that since height growth of understory trees

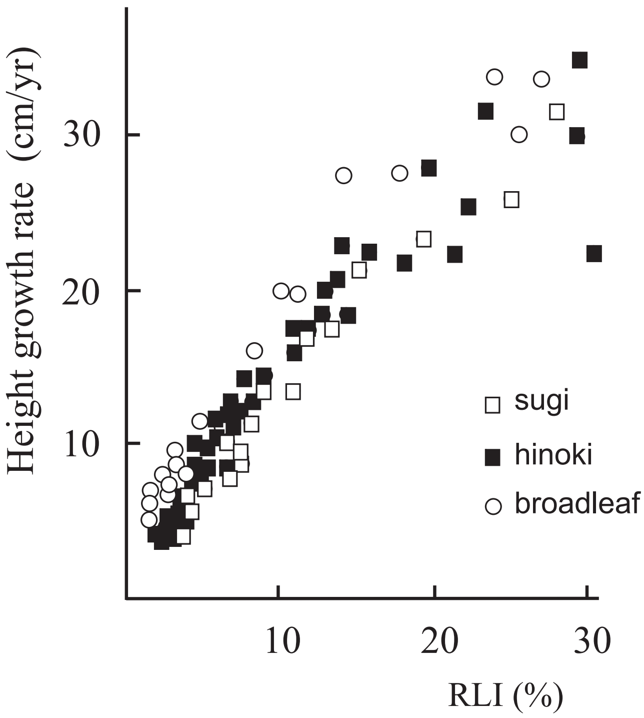

Fig. 5. Relationship between relative light intensity (*RLI*) and height growth rate of sugi seedlings under the forest canopies of sugi, hinoki and deciduous broadleaved trees.
Sugi seedlings measured were under the canopies of sugi (□), hinoki (■), and broadleaved (○) trees. Data from Waseda (1983).

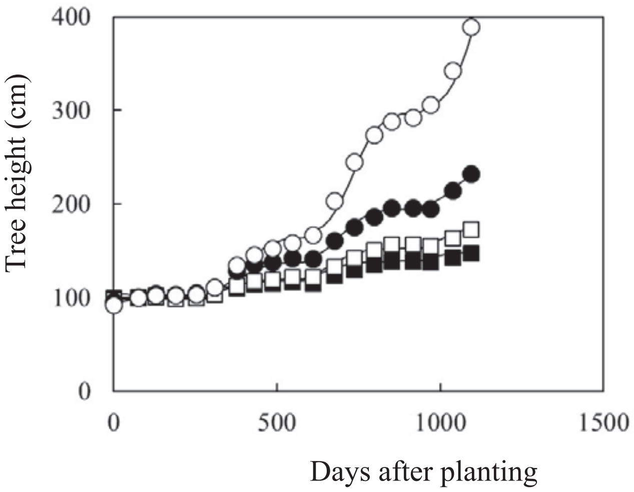

Fig. 6. Tree height of understory *Hopea odorata* trees beneath the forest canopy at different thinning intensities.
Solid lines show the regression curves expressed by a logistic function Eq.(2).
Symbols denote ○: GAP; ●: 2/3 thinning; □: 1/3 thinning; ■: no thinning.

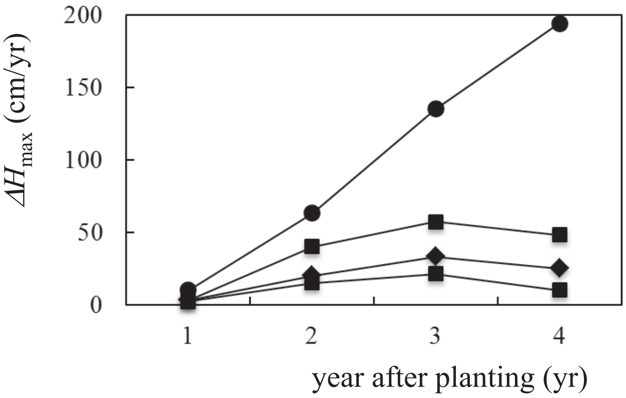

Fig. 7. Maximum height growth rates ΔH_{max} from Eq.(2) for the study plots with different thinning intensities.
Symbols are the same as in Fig.5.

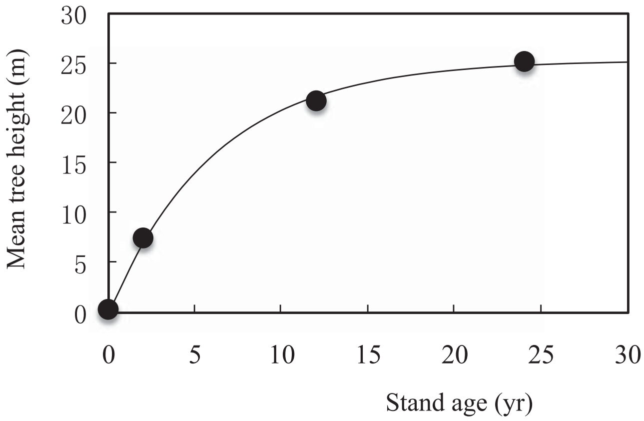

Fig. 8. Height growth of *Acacia mangium* in the plantation at Sakaerat Experimental Research Station.
Solid line shows the Mitscherlich growth curve approximated by Eq.(3).
Data from Kamo et al. (2009) and the present study.

should be closely correlated with the light environment under the canopy, ΔH_{max} is defined as being proportional to canopy openness or the sky factor. When we used equation (2), the simulated height growth rates of understory trees closely mirrored the actual data, even for the study plots with different thinning intensities (Fig. 6). Examining the values of the parameters λ, ΔH_0 and ΔH_{max}, it appears that λ and ΔH_0 may be constant irrespective of light environment and tree age. However, the ΔH_{max} values could be changed, as shown in Fig. 7. Although height growth rate in the gap increased steadily over the years, in the plots under forest canopy (2/3 thinning, 1/3 thinning or no thinning) the maximum rate was reached around three years after planting. This suggests that available light under the canopy decreased each year after the study plots were established in 2007. Although more careful parameterization is required, and environmental conditions should be recorded in detail at the study sites, the growth patterns of understory trees were well represented in the simulation (solid curves in Fig. 6).

4. Simulation approach for predicting forest development

The modeling tools for predicting the growth of understory trees were developed to take account of the canopy trees. That is, the models incorporate the effect of thinning on the canopy trees of plantation forests in order to evaluate light conditions under the forest canopy, and thus predict the growth patterns of understory trees. It appears that these models perform well with respect to simulating forest structure and growth associated with a variety of thinnings regimes, thus facilitating the selection of management strategies to promote the growth of understory trees.

However, additional measurements are required in order to evaluate the process of canopy closure and the response of understory trees after thinning and to validate the models. In particular, height growth of canopy trees is a key parameter for predicting the canopy closure of a study plot, through its correlation with crown width and crown length. Although most plantation forests in the tropics have been established using fast growing tree species such as *Acacia* and *Eucalyptus*, data pertaining to height growth rates of these genera after planting are lacking for Thailand. Fig. 8 illustrates the height growth data obtained at the Sakaerat Experimental Research Station, suggesting the maximum tree height in a 20-year-old stand to be about 25 m. However, the maximum tree height varies according to site conditions, which encompass factors such as nutrient availability, soil water status, and meteorological parameters.

$$H(t) = H_{\max} \left(1 - \exp(- a/H_{\max}\, t) \right) \quad (3)$$

where $H(t)$ denotes mean tree height in a stand age t, $H_{\max}$ is the maximum $H(t)$ and a is a constant. The parameters $H_{\max}$ and a for Fig. 8 were 25.3m and 4.09m/yr, and the coefficient of determination r^2 was 0.98.

In order to rehabilitate indigenous tropical forests via plantations of fast growing tree species, it will be necessary to model the tree growth process and the development of forest structure. This approach should allow us to simulate and examine the effects of thinning treatments on understory trees. Such simulations should be conducted in order to identify desirable forest management strategies to facilitate a succession from fast growing exotic species to indigenous canopy species.

Conclusions

It is required to introduce indigenous tree species on degraded land after the establishment of fast growing tree plantations. In an experimental two-storied plantation with the canopy trees (*Acacia mangium*) and the understory trees (*Hopea odorata*, *H. ferrea*, *Xylia xylocarpa* var. *kerrii*) in Thailand, the following simulation models were developed to evaluate thinning effects on the growth of canopy trees and to control the light environment so as to promote the growth of understory trees of indigenous species.

(1) A model to simulate the growth of canopy trees in response to thinning practices.
(2) “Virtual Forest” to evaluate the light environment under the forest canopy.
(3) A model to estimate the growth of understory trees.

These models were validated partly using the data collected in the plantation. By employing the models, adequate forest management plans can be selected heuristically, prior to any activity.

Acknowledgements

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A preliminary result of coppicing trials in teak plantations in Kanchanaburi, Thailand

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Abstract

The present study was carried out at Thong Pha Phum Plantation, Forest Industry Organization in Thong Pha Phum district, Kanchanaburi province. The objective was to study the growth parameters of coppice teak sprouts from stumps of thinning and final cutting which grew in the same area with the additional seedling. One-year-old teaks from coppices and seedlings that additional planting were measured at diameter at 10 cm above ground level (D_{10}), diameter at 30 cm above ground level (D_{30}) and diameter at breast height (DBH). The height growth of teak was also measured. The growth characteristics were compared between coppice sprouts and additional seedling.

Result indicated that the growth ability of coppice sprout of teaks was affected by origin of teak. The coppice sprouts from stump of final cutting were better than from stumps of thinning and additional seedling, while the coppice sprouts from stump of second thinning were better than from stumps of first thinning. The results showed that highly significant difference in all the size parameters among origin of teak trees was found (p<0.01). The coppice is one of the alternative regeneration systems not only by low cost, but also by enhancing the short rotation and productivity of plantation.

Keywords: growth, coppice, teak, plantations, Kanchanaburi

Introduction

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

FIO is the biggest and oldest company that owns teak plantations for the economic purpose in Thailand. FIO started growing teak in 1968 and the rotation length were 30 years in the good site and 40 years in the poor site, respectively. The interval of thinning cycles at 10, 15 and 20 years of age are practiced for good sites, while such intervals would be 15, 22 and 30 years of age for poor site.

In 1995, 2:2 mechanical thinning (2 lines cut and 2 lines remained) was conducted in FIO teak plantations for improvement the remained teaks. The coppice sprouts were occurred after thinning, but the growth was not well (Vacharangkura and Viriyabuncha 2003). The coppiced system was used after teak plantations were clear-cut in 2001. Some coppice sprouts regenerated combined with the additional planting for 80-90 trees/rai. In the past, FIO did not have the system for management the coppiced teaks, so they remained one or two coppice sprouts after coppiced. Since 2003, the best sprout in term of highest, strongest and nearest surface ground was remained. It was found that the sprout grow better than the additional tree. However, some plantations with intensive care were found that some additional tree could grow equal to sprout and the growth was not different in around 3 years. The primary advantage of coppice system was saved the costs of labor, stump and land preparation. The coppiced system was extensively employed in most of FIO's teak plantations. In present, there are few studies about the coppiced system.

This study aimed to examine the growth of coppiced teak for alternative management, expecting early incomes from fast-growing stems as well as cost-cutting in management. This system may allow farmers to improve the manner of combined management of agriculture and forestry that can be practiced by as many farmers as possible will be developed.

Materials and methods

This study was conducted at Thong Pha Phum Plantation belong to FIO in Thong Pha Phum district, Kanchanaburi province, western Thailand at the latitude of 14º8'-14º46'N and the longitude of 98º37'-98º46'E. It was considered a relatively superior site for teak plantation because its elevation of about 400 m. It was about 300 m below the upper limit for growing teak in Thailand. Thong Pha Phum Plantation's landform surrounded by limestone mountains. The climate of Thong Pha Phum Plantation is generally affected by monsoons and can be divided into hot, rainy and cold seasons. April is the hottest month with the average temperature of 36.7ºC, while January is the coldest with average temperature of 15.8ºC. However, critical minimum and maximum temperature might range between 6-42ºC. Rainy season starts from early May and end in late October with mean annual rainfall of 1,765 mm. Dry periods cover about 6 months, from early November to late April having only 187 mm of rainfall equivalent to 10.6% of the annual rainfall during such period.

The investigation was started in February, 2010 to December, 2010 at the teak plantation planted in 1980 with the original spacing of 4 x 4 m where the first thinning (50%) and second thinning (30%) were conducted when teaks were 15 years old and 22 years old, respectively. After the final cut in December, 2008, every coppice sprouts regenerated from stumps of first thinning, second thinning and final cutting in February, 2009 after they got the sufficient light. The best sprout (healthy, best growth rate and occurred from the lowest position of stump) was selected for retention in each tree after approximately 3 months. The additional planting by stump was done in around April to the beginning of May.

Three plots of 40 x 40 m size were laid out by using completely randomized design with 2 sites (Fig. 1). One-year-old teaks from coppices and seedlings that were additionally planted measured size parameters i.e. diameter at 10 cm above the ground level (D_{10}), diameter at 30 cm above the ground level (D_{30}) and diameter at breast height (DBH) every two months from February, 2010 to December, 2010. The heights of samples were also measured. The growth characteristics were compared between coppice sprouts and additional seedling was analyzed by Multiple Comparisons of Means: Tukey Contrasts (95% family-wise confidence level). Total initial number of coppices and planted seedlings measured were 54 sprouts and 26 seedlings in Site 1 and 66 sprouts and 13 seedlings in Site 2.

Fig. 1. Study sites

Results and discussion

1. Growth parameters of teak trees

Most of coppice sprouts grew after final cutting, because they can get the sufficient light. The seedlings were additionally planted at where the coppice sprouts couldn't grow. There was no coppice sprouts from first thinning stump in Site 1, but were found in Site 2.

(1) The share of coppices and seedlings

The sprouting of teak in this study were 59 % and 69 % in Site 1 and Site 2, respectively. The coppicing ability was less than in Mixed Deciduous Forest, Ngao District, Lampang (Chaweepuk 1999). The share of seedling

Table 1. The share of coppices and seedlings in the teak plantations in Thong Pha Phum

Sources	Site 1		Site 2	
	Number (tree/ha)	%	Number (tree/ha)	%
First thinning	0	0	100	17
Second thinning	125	22	156	26
Final cutting	213	37	156	26
Additional seedlings	181	31	81	14
Dead	56	10	106	18
Total	575	100	599	100

additionally planted was higher than coppices in Site 1. The number of sprouting from the stumps of second thinning, the stumps of final cutting and additional seedlings occupied 22 %, 37 % and 32 %, respectively. In contrast, share of additional seedlings were smaller than coppices in Site 2. The share of sprouts from the stumps of first thinning, second thinning, final cutting and additional seedlings were 17 %, 26 %, 26 % and 14 %, respectively, as showed in Table 1.

(2) Diameters

The tree size of seedlings additionally planted was the smallest among all categories, following those of coppice sprouts from second thinning and final cutting stumps. As same as in Site 2, teaks from seedlings additionally planted was the smallest and coppice sprouts from first thinning, second thinning followed and final cutting was the largest. The two years old additional seedling was the smallest.

1) D_{10}

The D_{10} of additional seedlings in site 1 increased from 0.76 cm in February, 2010 to 2.49 cm in December, 2010. The D_{10} of coppice sprouts from stumps of second thinning and final cutting increased from 1.68 cm to 4.30 cm and from 3.49 cm to 5.96 cm, respectively. In Site 2, D_{10} of additional seedlings (0.52 cm to 1.85 cm) were smaller than those in Site 1. On the other hand, D_{10} of coppice sprouts from stumps of both second thinning (4.93 cm to 7.16 cm) and final cutting (5.66 cm to 8.55 cm) were larger than those in Site 1. In both sites D_{10} of coppice sprouts from stumps of final cutting were the largest and coppice sprouts from stumps of second thinning and additional seedling followed it. D_{10} of coppice sprouts from first thinning stump could find only in Site 2, and their D_{10} increased from 3.40 cm to 6.26 cm. Those were smaller than other coppice sprouts, but larger than additional seedlings.

2) D_{30}

The results in Site 1 showed that D_{30} of additional seedling increased from 0.84 cm in February, 2010 to 2.13 cm in December, 2010. The D_{30} of coppice sprouts from stumps of second thinning and final cutting increased from 1.42 cm to 3.47 cm and from 2.94 cm to 5.13 cm, respectively. In Site 2, D_{30} of additional seedlings (0.56 cm to 1.74 cm) were smaller than those in Site 1. On the other hand, D_{30} of coppice sprouts from stumps of both second thinning (4.43 cm to 6.20 cm) and final cutting (4.77 cm to 7.42 cm) showed bigger than those in Site 1. D_{30} of coppice sprouts from stumps of thinning and final cutting were bigger than additional seeding in both sites. D_{30} of coppice sprouts from first thinning stumps could find only in Site 2 increased from 3.05 cm to 5.35 cm were smaller than coppice sprouts from stumps of second thinning and final cutting, but bigger than additional seedlings.

3) DBH

Because the additional seedlings were very small, few seedling could be measured DBH. DBH of additional seedling increased from 1.77 cm in August, 2010 to 2.27 cm in December, 2010 in Site 1 and 1.00 cm to 3.30 cm in Site 2. The DBH of coppice sprouts from stumps of second thinning and final cutting were 1.95 cm to 2.59 cm and 2.57 cm to 3.89 cm, respectively in Site 1. In Site 2, the DBH of coppice sprouts from stumps of first thinning, second thinning and final cutting were 2.87 cm to 4.20 cm, 4.05 cm to 5.35 cm and 3.70 cm to 5.73 cm, respectively. The same trend as D_{10} and D_{30}, coppice sprouts from stumps of final cutting were biggest followed by those from stumps of second thinning, first thinning, and additional seedling. DBH of coppiced teak at TPC Clone Bank, Uthai Thani Province was 4.58 cm at the age of 12 months (Thueksathit 2006) showed bigger than those in Site 1 but smaller than those in Site 2. Comparison the DBH of coppice sprouts between sites showed that in Site 2 were bigger than in those in Site 1.

(3) Height

Total height also showed the same trend of diameter. The height of additional seedlings was 0.24 m to 0.96 m in Site 1 which showed higher than in Site 2 (0.16 m to 0.51 m). On the other hand, height of coppice sprouts from stumps of second thinning and final cutting in Site 1 were 0.53 m to 1.80 m and 1.39 m to 2.95 m showed smaller than those in Site 2. The height of coppice sprouts from final cutting showed highest in both sites and higher than the height of 1-year-old coppiced teak at TPC Clone Bank, Uthai Thani Province (2.25 cm)

The results indicated that coppice sprouts grew faster than seedlings as showed in Fig. 2-3.

2. Growth parameters comparison

The size parameters among by the origin in Site 1 and Site 2 shown in Tables 2 and 3.The coppiced teak grew from the stump of second thinning and from final cutting showed the growth in term of D_{10}, D_{30} and height better than those of additional seedling in Site 1. In Site 2, the growth parameters showed highest in coppice from stumps after final cutting and lower in coppice from stump after thinning (first and second thinning) and additional seedlings, respectively. The results from comparison the growth parameters of coppice sprouts from stumps after thinning, stumps after final cutting and additional seedling in both

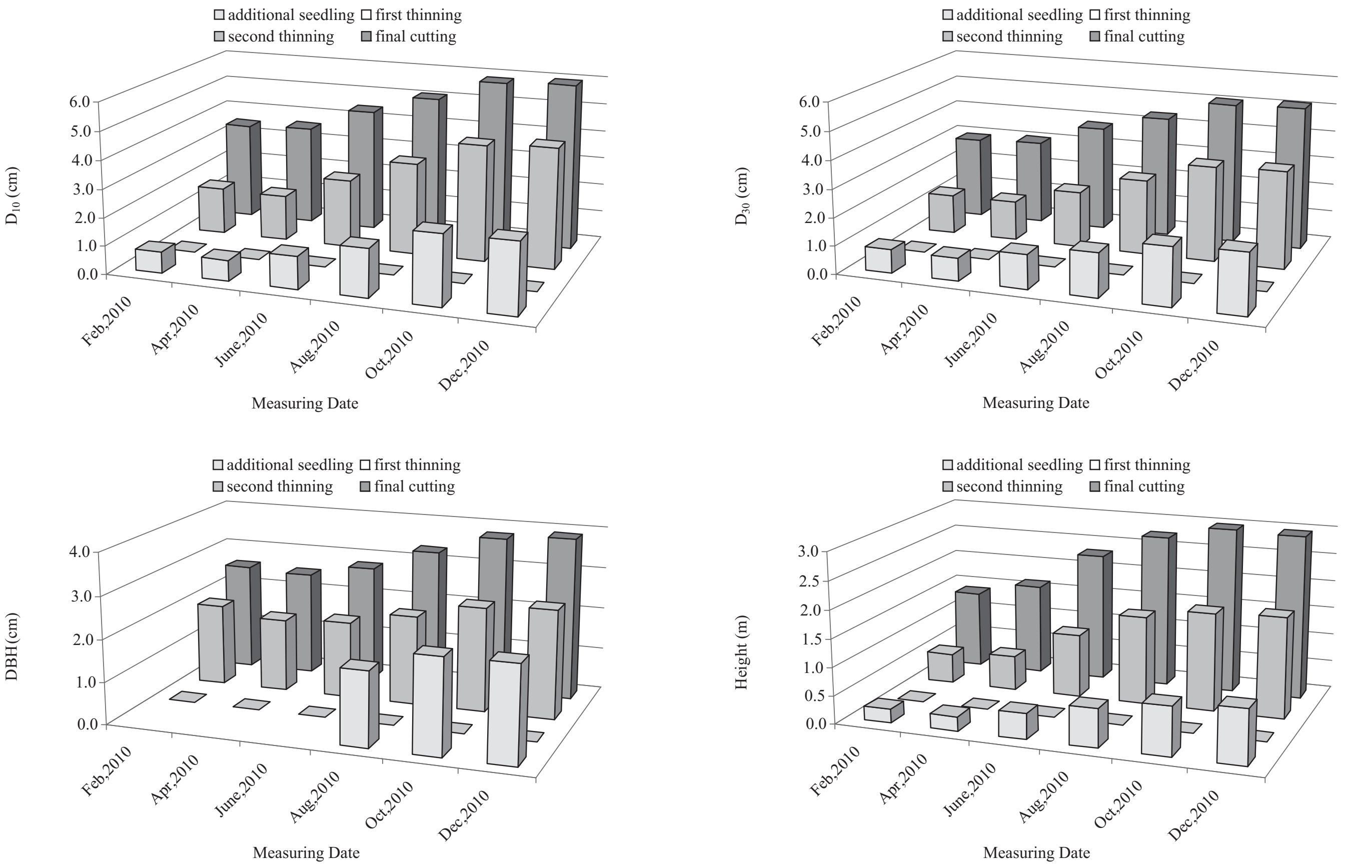

Fig. 2. Growth parameters of coppice sprouts and additional seedling in Site 1

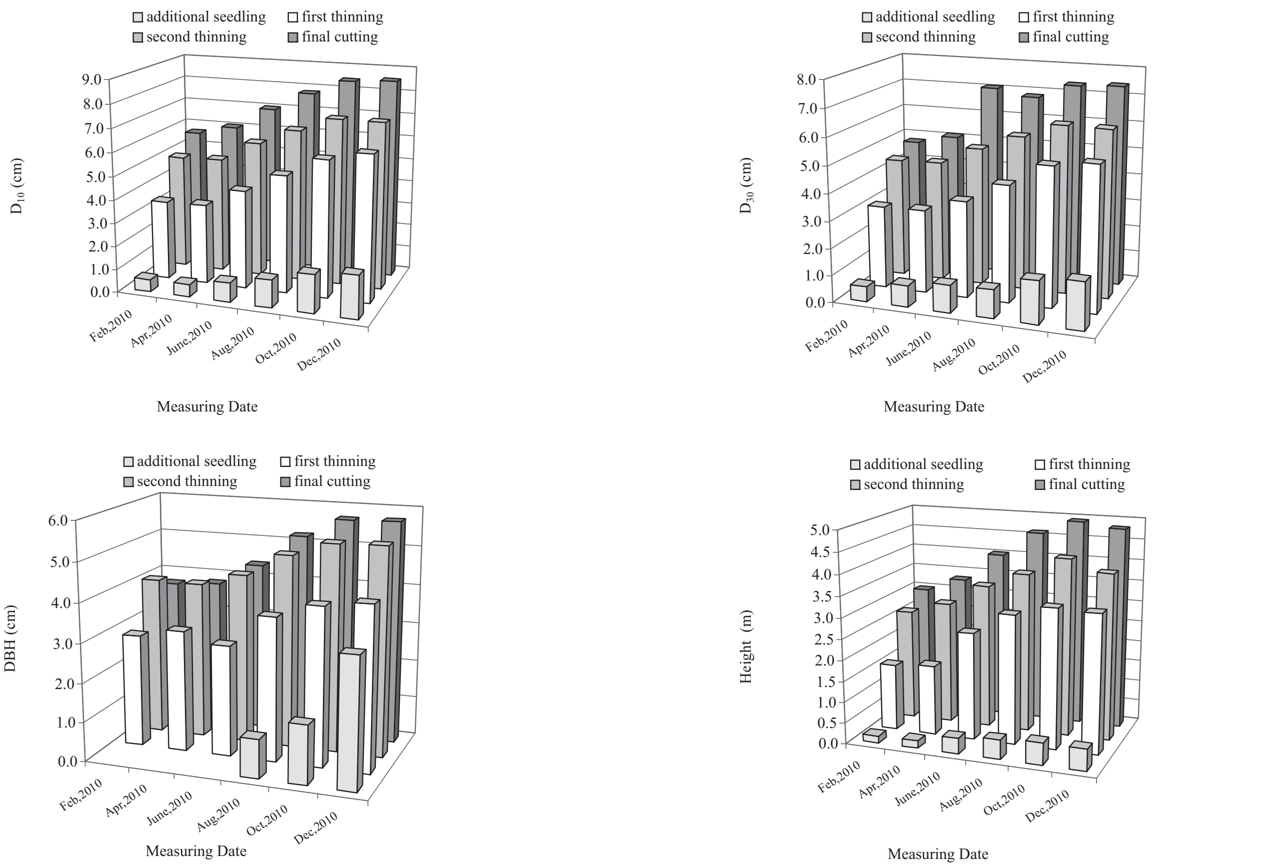

Fig. 3. Growth parameters of coppice sprouts and additional seedling in Site 2

Table 2. Comparison growth parameters among the sources of teak in Site 1

Parameters	Sources	Mean	S.D.	F value	*p* (>F)
D_{10} (cm)	Additional seedling	1.55 a	1.10	570.00	0.0000
	Second thinning	2.91 b	1.52		
	Final cutting	4.73 c	1.97		
D_{30} (cm)	Additional seedling	1.67 a	0.90	328.96	0.0000
	Second thinning	2.47 b	1.17		
	Final cutting	4.06 c	1.75		
Height (m)	Additional seedling	0.56 a	0.56	498.78	0.0000
	Second thinning	1.23 b	0.78		
	Final cutting	2.33 c	1.28		

All difference are significant at the 0.01 level ($p < 0.01$)

Table 3. Comparison growth parameters among the sources of teak in Site 2

Parameters	Sources	Mean	S.D.	F value	*p* (>F)
D_{10} (cm)	Additional seedling	1.10 a	0.79	216.75	0.0000
	First thinning	4.71 b	2.47		
	Second thinning	6.11 c	3.78		
	Final cutting	7.25 d	2.72		
D_{30} (cm)	Additional seedling	1.41 a	1.06	72.23	0.0000
	First thinning	4.13 b	2.18		
	Second thinning	5.37 c	3.37		
	Final cutting	6.42 d	4.13		
Height (m)	Additional seedling	0.37 a	0.27	196.54	0.0000
	First thinning	2.59 b	1.60		
	Second thinning	3.51 c	2.41		
	Final cutting	4.12 d	1.83		

1. All difference are significant ($p < 0.01$)
2. Means followed by a different letter are significantly different ($p < 0.01$) (a, b).

Table 4. Size parameters comparison between the study sites

Parameters	Sites	Mean	S.D.	F value	*p* (>F)
D_{10} (cm)	Site 1	3.06	2.10	457.69	0.0000
	Site 2	5.32	3.44		
D_{30} (cm)	Site 1	2.96	1.74	349.47	0.0000
	Site 2	5.04	3.47		
Height (m)	Site 1	1.39	1.22	1908.5	0.0000
	Site 2	4.39	2.18		

All differences are significant at the 0.01 level ($p < 0.01$)

sites showed highly significant difference among the origin of young trees.

The results also indicated that the average D_{10} of coppiced teak trees were 3.06 cm and 5.32 cm in Site 1 and Site 2, respectively. The average D_{30} of coppiced teak trees were 2.96 cm in Site 1 and 5.03 cm in Site 2. As same as the average height of coppiced teak trees were 1.39 m in Site 1 and 4.38 m in Site 2. The coppice sprouts in Site 2 grew from the stumps of first thinning and second thinning, it meant that the coppice ability in Site 2 showed better than in Site 1. The results also indicated that D_{10}, D_{30} and height of teak trees in Site 2 were better than those in Site 2. Based on statistical analysis, D_{10}, D_{30} and height were found to be significantly different at 95% confidence level between two study sites. There were few data, DBH were not analyzed in this study. The mean of size parameters in both study sites are shown in Table 4.

The result showed that the coppice growth depended on light condition, because most coppices grew after the final cutting. Additionally, coppice ability depended on the age of the stump, because growth parameters (D_{10}, D_{30}, DBH, and Height) of coppices from stumps of final cutting were higher than those from the thinned stumps. Moreover, the coppices grew faster than the additional seedlings perhaps due to the stock of dry matter in the stumps. However, the growth of coppices was faster than those of the additional seedlings in the same area, but the difference was smaller when teak was getting older. Himmapan (2008) indicated that the growth characteristics, including DBH, height, basal area, stem volume and biomass of teak coppices were dramatically increasing during 2-3 years old, while slightly increasing in the age of 8 years.

The coppiced teak is one of the alternative management. Coppice system may achieve early incomes from fast-growing stems, as well as cost-cutting in management. Teak stumps after clear-cutting could be left for self-coppicing which in turn will reduce the cost in both new seedling and site preparation (Akkhaseewon 2007). Himmapan (2008) found that coppice method at a teak plantation with 4 x 4 m spacing decreased the cost of land preparation, planting, first weeding, and fertilizing. It was estimated that management cost at the first year was reduced from the normal cost (3,960 Baht/rai) to 2,028 Baht/rai, if coppicing rate was 50 %, and it reduced to 2,203 Baht/rai, if coppicing rate was 70 %.

Conclusion

Growth of the coppices of teak varied by their origin e.g. from the stumps of thinning and final harvesting. Growth performance of the coppices from clear-cut stumps was better than those from the thinned stumps. Moreover, growth of the coppices from the second thinned stump was better than those of the first thinned stumps. Using coppice could be one of the alternative agents to promote regeneration which will achieve both low cost and early income.

Advantages of coppice silviculture were found not only in the higher growth rate than seedlings, but also in deceasing management cost. This system may reduce the burden of weed management, physical protection of the site and negligible risk of erosion.

Acknowledgements

We would like to express our appreciation to the Thong Pha Phoom Forest Plantation, Forest Industry Organization, Kanchanaburi Province for giving us chance for setting experimental plots in teak plantations and kind support everything during collecting data. This study was carried out as part of joint research project between RFD and JIRCAS under the program for the development of combined management techniques for agriculture and forestry to support farmers who were engaged in planting beneficial indigenous tree species.

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Two-year results of a clonal test of teak (*Tectona grandis* L.f.) in the Northeast of Thailand

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Abstract

Clonal test had been conducted at Udon Thani and Khon Kaen provinces to determine difference of tree performances among clones at different sites and to produce improved genetic materials of teak for planting in the Northeast region. The experiment was undertaken with randomized completely block design (RCBD) with four replications. One replication contained three ramets of each clone planted in row. Fifty clones were selected based on previous field trail studies and shooting ability of the seedlings. Total seedlings of 600 seedlings/ sites (50 clones x 3 tree plot x 4 replications) were planted.

The preliminary results on survival rate, height (H) and diameter at root collar (D0) had been conducted when the seedlings reached three months, one year and two years. At two years, survival rate of the seedlings in Udon Thani and Khon Kaen was 68% and 70% respectively. In general, it was likely that the growth rate in terms of H (1.17 m) and D0 (2.99 cm) was relatively poor at both sites. However, H & D0 in Udon Thani (1.30 m, 3.05 cm) was slightly higher than those in Khon Kaen (1.02 m, 2.93 cm). In terms of clone performances, statistical analysis showed that there was no significant difference in H & D0 of seedlings among clones on the two sites. There was no interaction effect between site and clone on H & D0.

Keywords: *Tectona grandis*, clonal test, clone, Northeast Thailand

Introduction

A number of research projects regarding teak improvement program had been conducted in Thailand since 1965 when the teak improvement program had been initiated. The first seed orchard in Thailand was established in 1965 at Maegar seed orchard, Phayao province. In 1966, the provenance test of 30 provenances was established in Lampang province. It was found that at eight years old, Ngao provenance (S88) from Lampang province showed the best performance in terms of height.

As for clonal test, major field trials had been conducted in 2000. In order to reselect teak plus trees and select suitable clones to be planted various sites, four sets of 100 clones test were planted in three sites *i.e.* Songkhla, Kanchanaburi, Kamphaeng Phet. The first set of clonal rooted cutting seedlings was planted in 2000. Results of the first evaluation when the trees were 5 year old showed that sites significantly affected to both total height and DBH. The results showed that within site clones significantly affected DBH in all sites. In other words, The DBH among clones was significantly different in all sites. While significantly affected height only in Kamphaeng Phet site. There were interaction effects between clone and site on both total height and DBH. In brief, the results indicated that selection of suitable clones for plantation site properties must be taken into consideration.

There was no information of clonal test in spite of recent emerging private teak plantation forestry by farmers in Northeast Thailand, so far. The objectives of this study were to determine difference of tree performances among clones at different sites in NE and to produce improve genetic materials of teak for planting in the NE areas.

Materials and methods

Experimental Plots at two sites (51.25 ha each) were determined as follow:- I. Tambon Noonsomboom, Banhaed Sub-district, Khon Kean Province (nearby Northeast Forest Seed Center), and II. Tambon Dutung, Muang District, Udon Thani (nearby Plantation Extension Center no.9). Top 49 clones were selected based on previous clonal test

324	5ค/3	115	335	ข2/40	289	ข4/87	38	ค5/47	331	300	ค1/46	ก4/9	330	ค5/47	119	ข1/28	28c60	317	ค4/19
39	273	3จ/2	ข1/28	91	X5	251	ค4/19	343	263	ข4/87	3จ/7	39	ง1/18	289	5ก/34	273	29	ก5/28	336
ข1/29	4ค/24	29	336	ง1/18	267	3ก/14	X3	271	ก4/9	335	267	x5	251	5ก/33	115	343	ก4/38	263	245
300	302	5ก/34	130	333	จ2/33	3จ/7	35	317	305	ข1/29	5ค/3	324	จ3/23	35	305	3ก/14	38	333	302
5ก/33	119	ก5/28	26c17	28c60	245	330	จ3/23	ก4/38	ค1/46	91	333	26c17	3จ/2	271	4ค/24	130	ข2/40	จ2/33	x3
305	ข1/28	251	4ค/24	317	ง1/18	39	จ2/33	336	ข1/29	273	ค1/46	ก5/28	130	ข2/40	28c60	จ3/23	289	ค5/47	ข4/87
28c60	35	3จ/2	271	ก4/38	130	300	5ก/34	119	343	336	115	5ก/33	4ค/24	263	38	330	ข1/29	26c17	271
245	263	333	x3	91	335	26c17	29	ก4/9	289	305	x3	35	302	ก4/9	331	245	335	39	300
302	3จ/7	ค1/46	38	3ก/14	x5	267	จ3/23	324	ค4/19	251	324	3จ/2	จ2/33	91	343	3จ/7	29	5ค/3	ค4/19
ข2/40	331	330	ก5/28	5ค/3	ข4/87	115	5ก/33	ค5/47	273	ก4/38	ง1/18	119	3ก/14	5ก/34	267	ข1/28	x5	317	333

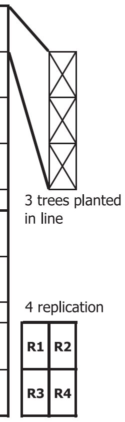


Fig. 1. Planting design (low-column design) of teak clonal test of 50 clones (4 replications x 3 tree plots)

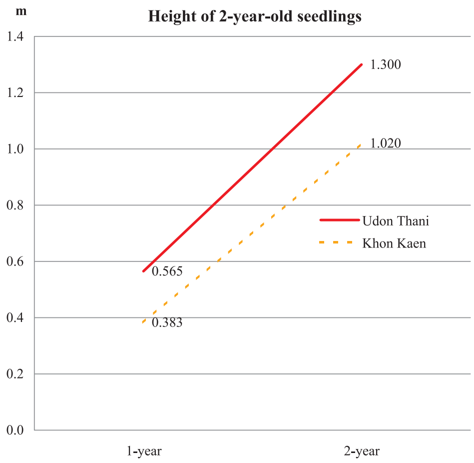
Fig. 2. Examples of teak seedlings at 2 year after planting (Left); Clone no.115 of replication no.1. (Right); Seedling planted at Khon Kaen was monitored on height and diameter at root collar

studies (27 selected clones from 100 clones of clonal test planted in 2000, 22 clones from cross-controlled pollination) excluding (unselected) clones used as a control treatment. Stock plants were prepared by tissue culture. Experimental design was randomized complete block design (RCBD) with 4 replications and one replication containing 3 ramets of each clone planted in row (Fig. 1). In 2008, seedlings were planted on September, and August at Khon Kaen and Udon Thani Provinces, respectively. Monitoring growth in terms of height (H) and diameter at root collar (D0), survival rate and determine clone x site interaction. Analysis of variance (ANOVA) was used to determined variation of growth among clones.

Results

The preliminary results were monitored when the trees reached one year and two years old (Fig. 2). Survival rate, height, and diameter at root collar (D0) were measured and statistically analyzed. The major findings were as follow:-

1) The survival rate of the seedlings in Udon Thani (68%) was similar to those in Khon Kaen (70%).
2) Growth rate of one and two years old was similar. Height (H) and Diameter at root collar (D0) in Udon Thani was slightly larger than in Khon Kaen.
3) At one year old, average H and D0 in Udon Thani (n= 429) was 56.54 cm (SD=49.34) and 18.10 mm (SD= 9.09), respectively; And H and D0 in Khon Kaen (n = 534) was 38.30 cm (SD=21.19) and 10.66 mm (SD=0.56 mm), respectively (Fig. 3).
4) At two years old, average H and D0 in Udon Thani (n = 408) was 1.30 m (SD=0.87) and 3.05 cm (SD=1.34), respectively; And H and D0 in Khon Kaen (n=422) was 1.07 m (SD=0.61) and 2.93 cm (SD=1.25), respectively (Fig. 3).
5) Statistical analysis showed that there was no significant difference in H and D0 of seedlings among clones on the 2 sites. Besides, there was no interaction effect between site and clone on H and D0. (Tables 1 and 2).



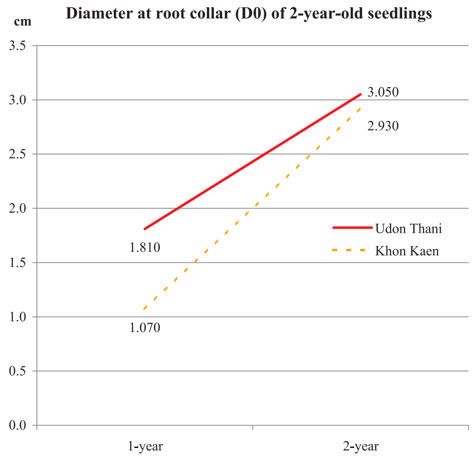


Fig. 3. Growth of two years old teak seedlings

Table 1. Statistics for Height of 2 years old seedlings at the two sites

	df	F	*p*-value	Remarks
Block	3	14.60	0.0001	Highly sig.
Site	1	16.40	0.0001	Highly sig.
Clone	50	0.91	0.6494	Non sig.
Site x Clone	48	0.81	0.8370	Non sig.
Site x Block	2	17.36	0.0001	Highly sig.

Table 2. Statistics for Diameter at root collar (D0) of 2 years old seedlings at the two sites

	df	F	*p*-value	Remarks
Block	3	13.35	0.0001	Highly sig.
Site	1	1.44	0.2309	Non sig.
Clone	50	1.10	0.3158	Non sig.
Site x Clone	48	0.90	0.6683	Non sig.
Site x Block	3	12.36	0.0001	Highly sig.

Table 3. Comparison of soil type and soil condition between the good & poor sites on growth and stem form of teak

		Teak Preferences	Planting Site
Soil Type		Sand-loam	Loam-sand
		Alluvial soils	Acidic soil (pH<6)
Soil Condition	Depth	Deep	Shallow
	pH	6.5-7.5	5.5
	Porosity	High	Low
	Drainage	Well	Poor-compacted or waterlogged soil in particular when wet)
	Moisture-holding capacity	Poor	High

Discussions

Teak grew best on deep, well-drained alluvial soils derived from limestone, schist, gneiss, shale (and some volcanic rocks, such as basalt). The optimum pH range for better growth and quality was within 6.5-7.5. Conversely, the species performed very poor, in terms of growth and stem form, on dry sandy soil, shallow soil (hard pan soil or lower water table soil), acidic soil (pH < 6.0) derived from laterite or peatbog, and on compacted or waterlogged soil (Kaosa-ard 1981; Tewari 1992).

The growth rate in terms of H and D0 of the seedlings reported in the present study was considered as low. The possible explanation for this was due to negative impact of the environmental factors in terms of soil and climate. Soil types and soil condition of the planting site was non-preferences for teak. Soil was considered as acidic soil (pH 5.5) (Table 3). In addition, both plots faced irregular climate situations for example, drought for long period after planting, The Khon Kaen plot also experience severe flooding after planting around few weeks.

We conclude that the low rate of growth was primarily related to unsuitable condition both non-preference soil for teak and severe flooding and drought as well. We, however, founded that the tested trees could somehow adapt themselves to the sites; therefore tree performances among clones, genotypic value, determine optimum age for selection could be detected in the future (at least after 5 years old). Further monitoring shall be organized.

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A preliminary result of soil improvement trial on teak in Khon Kaen, Thailand

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Abstract

A study on soil improvement for planting teak (*Tectona grandis*) was carried out at Northeastern Forest Seed Center, Ban Had District, Khon Kaen Province, Thailand. The experimental design was randomized complete block with 3 replications. The trees were planted at 2 m x 4 m spacing. Five different soil improvement methods (treatments) were applied, including 1) Control (no treatment) 2) Application of dolomite (400 kg/rai) 3) Application of dolomite (400 kg/rai) and organic fertilizer (1 kg/tree) 4) Application of dolomite (400 kg/rai) and chemical fertilizer (100 g/tree x 2 times) and 5) Application of mixed fertilizer (dolomite + organic fertilizer + chemical fertilizer at (100 g /tree x 2 times). Height of the trees was recorded. The composite soil samples in each subplot prior to application of soil improvement materials were collected and analyzed for some chemical and physical properties. The surface soil moisture in each subplot was measured using theta probe type ML2x. The preliminary results showed that there was no significant difference in height growth of teak at 15 months after planting. There were no significant differences in almost all studied soil properties except for soil pH and organic matter.

Keywords: teak, *Tectona grandis*, soil improvement, tree growth, soil property

Introduction

Thailand is one of the countries known as teak natural stands. Natural teak distribution lies mainly in the northern and the western part of Thailand. Although teak can grow over a wide range of edaphic conditions, the quality and distribution of natural teak is related to the nature of underlying rock which reflects its soil conditions. The physical and chemical properties of soil such as texture, depth, porosity and drainage are deciding factors in determining the growth quality of teak. Teak requires deep, moist, fertile and well drained sandy loam soils (Kadambi 1951; Kaikini 1956). Teak prefers basic to acidic soils and can grow well in soils where pH values ranges between 6.5 and 7.5. However some studies showed that teak could also grow well even in acid soils (Puri 1951; Pande and Sharma 1986; Banerjee et al. 1986). Several soil characteristics including soil moisture, cation exchange capacity, base saturation, phosphorus and calcium content in soils were also found to be association to teak growth (Beumea and Beckman 1956; Kotwal 1959; Yadav and Sharma 1967; Jungsuksuntigool and Wichiennopparat 1994).

Due to continuous high demand on teak and short supply of teak from natural stands, teak plantation is an important source for constant supply for teak. However the areas with favorable site and soil conditions for teak growth are limited. The Japan International Research Center for Agricultural Sciences (JIRCAS) and the Royal Forest Department (RFD) have established a collaborative project entitled “Development of Techniques for Nurturing Beneficial Indigenous Tree Species and Integrated Management of Agriculture and Forestry in Northeast Thailand, Tropical Monsoon Regions”. This study is under one of the two subprojects aiming to find appropriate soil improvement techniques to promote better teak growth in the Northeastern of Thailand where the soils are generally acidic and sandy with less fertility compared to other parts of the country. The know−how and techniques gained from this study would be further extended to the farmers in the regions.

Materials and Methods

The study site was located at the Northeastern Forest Tree Seed Center, Ban Nonesomboon, Tambon Nonesomboon, Ban Had District, Khon Kaen Province in

Fig. 1. Location of the study site

the northeastern part of Thailand (Fig. 1).

The experimental design was randomized complete block design with 3 replicates (blocks). Five treatments (soil improvement methods) including A) Control (no treatment) B) Application of dolomite (400 kg/rai) C) Application of dolomite (400 kg/rai) and organic fertilizer (1 kg/tree) D) Application of dolomite (400 kg/rai) and chemical fertilizer (100 g/tree x 2 times) and E) Application of mixed fertilizer (dolomite + organic fertilizer + chemical fertilizer at (100 g/tree x 2 times) were randomly assigned to each subplot. Each subplot was surrounded by buffer. The size of the subplot was 18 m x 28 m. The seedlings were planted with 2 m x 4 m spacing.

The soil pits were dug at the study area prior to site preparation to investigate the under lied soil conditions. The experimental area was ploughed by using farm tractor. Soil improvement materials were applied accordingly as described earlier. Teak seedlings were prepared by using tissue culture technique. The clone number used was 38. The seedlings were planted in August 2009. The composite soil samples in each subplot were collected at 3 depth levels (0−15, 15−30 and 30−50 cm) prior to application of soil improvement materials and were, then, analyzed for some chemical and physical properties. Total height of all trees was recorded at 1, 6, 12 and 15 months old. Growth and soil data were analyzed by using the statistical package GENSTAT. The surface soil moisture in each subplot was measured using theta probe type ML2x.

Results

1. Soil conditions

We dug three pits for clarifying under lied soil property in spite of the small area of experimental site since there was apparent difference in vegetation under the plantations. (Fig. 2). The results of the range of some soil characteristics from the three soil profiles were given in Table 1. The physical and chemical properties of soil at each pit did not differ except the content of exchangeable cations and soil texture of the B_2 horizon.

The results of the analysis of composite soil samples collected at the depth of 0−15, 15−30 and 30−50 cm showed that most of chemical and physical soil properties under different treatments prior to planting were not significantly different except for soil organic matter content in the upper two layers, but the difference was not in big amount because the organic matter content of all the samples were low (less than 1%). The analyzed values of all study soil characteristics generally fell in the similar range of those found in the soil profiles shown in Table 1. The soils also contained low available phosphorus (0.6 to 4.6 ppm). The soil texture of almost all samples was sandy and small portions were sandy clay loam.

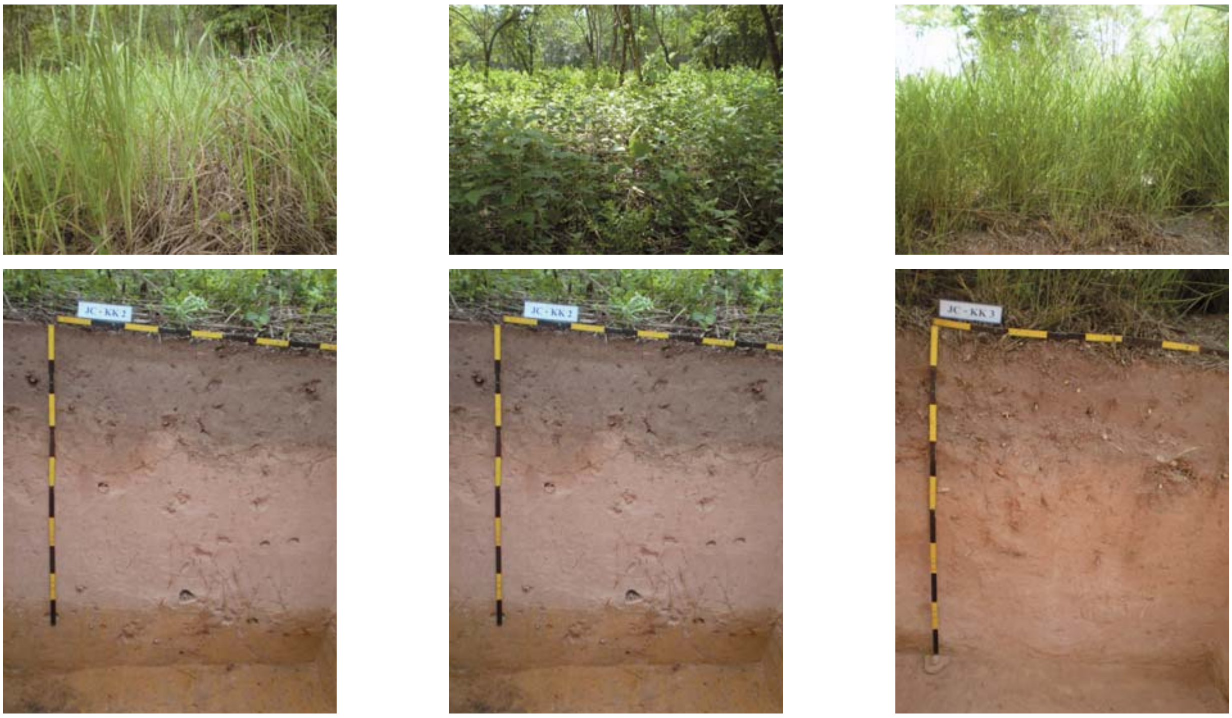
The surface soil moisture distribution monitored under different timing representing rather dry, moderately moist and wetter condition were shown in Fig. 3. Despite the wetter soil moisture found in one corner of the study plot, it showed no significant effect on teak growth at this stage.

2. Growth

The growth performance of teak at 1, 6, 12 and 15 months old in the study area was shown in Fig. 4. It was apparent that the growth of teak in the plots with application of dolomite and chemical fertilizer (treatment D) and in the plots with application of mixed fertilizer (treatment E) were better than those in other plots although no statistically significant difference was detected at 15 months (Fig. 5). The teak in control plots also showed good height growth despite no soil improvement material was applied.

Table 1. Some soil characteristics of the soil profiles in the study area

Horizon	Depth (cm)	Organic matter (%)	pH	Avail. P (ppm)	Exchangeable Cations (ppm)				Texture
					K	Ca	Mg	Na	
A	0 – 21/35	0.72 − 0.94	4.9 − 5.5	2 − 5	51 − 59	212 − 364	47− 50	5 − 9	Sandy
B_1	21/35 − 55/100	0.07 − 0.12	4.9 − 5.8	nil − 3	8 − 20	50 − 98	10 − 40	2 − 7	Sandy
B_2	55/100 − 120+	0.04 − 0.28	4.9 − 5.1	nil − 3	12 − 94	34 − 600	15 − 307	7 − 9	Sandy/ Sandy clay loam



(a) Soil profile under *Imperata cylindrical*

(b) Soil profile under *Chromolaena odoratum*

(c) Soil profile under *Arundinaria pusilla*

Fig. 2. Soil profiles at the study site

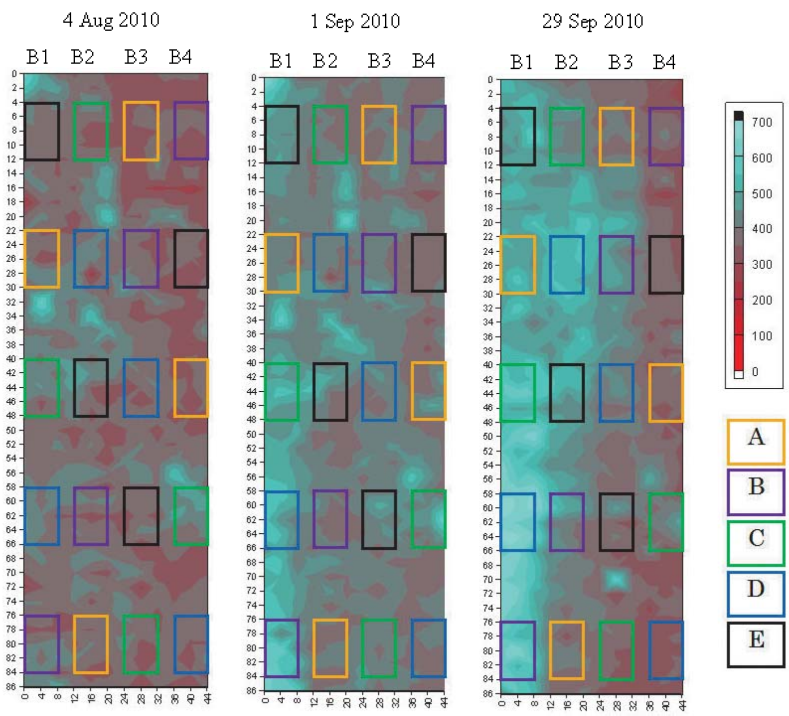


Fig. 3. Surface soil moisture distribution monitored under different timing representing rather dry, moderately moist and wetter condition

A = Control (no treatment)

B = Application of dolomite (400 kg/rai)

C = Application of dolomite (400 kg/rai) and organic fertilizer (1 kg/tree)

D = Application of dolomite (400 kg/rai) and chemical fertilizer (100 g/tree x 2 times)

E = Application of mixed fertilizer (dolomite + organic fertilizer + chemical fertilizer (100 g/tree x 2 times))

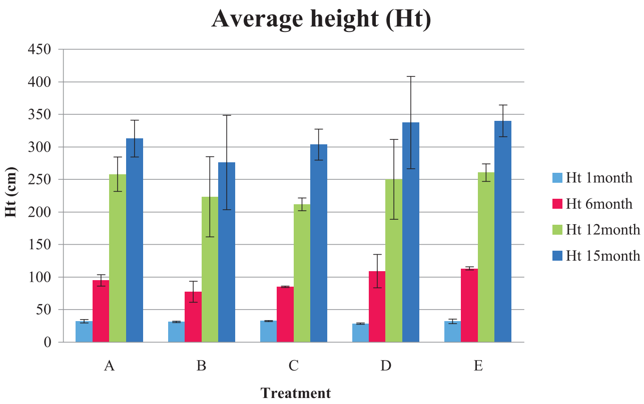


Fig. 4. Height development of teak clone no.38 under different soil improvement conditions

Fig. 5. Growth performance of teak at 15 months old in the study area

Conclusions and Discussion

The result of this study revealed that the improvement of soil quality in the Northeast of Thailand was needed to promote better teak growth, but at this early stage, there was no significant difference effect in teak growth either from the treatment applied or from the soil characteristic of each treatment. However, general conclusions and discussion could be drawn from this study as follow:−

1. The study area was one of major soils types found in northeast of Thailand. The soils were acidic and sandy with low nutrient content especially in organic matter and available phosphorus which might be limiting factors for teak growth.
2. No significant effect on fertilization with dolomite was detected at 15 months.
3. Soil moisture of the deeper layer could be another possible key factor governs teak growth so that further investigation is required.
4. From the results of the teak growth in control plots, it is likely that teak clone no. 38 may perform good growth in acidic soils with limited nutrient content.
5. Organizing systematic study on the relation between teak growth and soil property is required in various soil types to clarify the soil preference of teak in Northeast Thailand.

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Improvement of soil suitability mapping for teak plantations in Northeast Thailand

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Abstract

This study aimed to improve soil suitability mapping for teak (*Tectona grandis*) plantation in northeast Thailand. The study areas were in Udon Thani and Nong Bua Lam Phu Provinces. We checked soil properties and classified teak growth class by field surveys, and compared the soil suitability class with the teak growth class. The soil suitability classes were revised from three classes to five classes. The results of Udon Thani Province showed that moderately suited areas accounted for 42.3% (462,086 ha) mostly in the east part of Province, and not suited area 23.6% (257,626 ha) mainly in the central part. Nong Bua Lam Phu Province showed that moderately suited and more suited areas accounted for 37.4% (151,524 ha) mainly in north and central part of Province, and unsuited areas 29.1% (118,046 ha) mostly in the south part. But the ratio of suited areas was supposed higher in Nong Bua Lam Phu Province, due to more mountain area than Udon Thani Province.

The map accuracy was investigated by comparing the revised soil suitability class from soil group with actual teak growth class, and resulted that 20 sites were accord (69 %), five sites were underestimated (17 %) and four sites were overestimated (14 %). The map accuracy remained at 69 % to be acceptable. The farmer's management was supposed as an important factor, which affected to raise the teak growth class than corresponding to the revised soil suitability class.

Keywords: teak plantation, site suitability, soil group, mapping, farmer

Introduction

Teak is the well-known and valuable timbers of the world (White 1992; Kaosa-ard 1998; Robertson 2002 etc.) Its timber qualities include attractiveness in color and grain, durability, lightness with strength, ease of seasoning without splitting and cracking, ease of working and carving, resistance to termite, fungus, and weathering, etc.(Kaosa-ard 1998). Teak plantations have been widely established throughout the tropics with the main objectives to produce high quality timber. However, there are many factors limiting the success of teak plantation establishment, especially three main factors of site quality, seed supply and silvicultural management, affect growth and quality of the plantation (Kaosa-ard 1998).

On the basis of previous studies, Kaosa-ard (1998) said that teak grows best on deep, well-drained alluvial soils derived from limestone, schist, gneiss, shale. The species performs very poorly, in terms of growth and stem form, on dry sandy soil, shallow soil, acidic soil derived from laterite or peat bog, and on compacted or waterlogged soil (Kaosa-ard 1981 etc.). Roots were stunted and the taproot was very poorly developed in waterlogged alluvial soils and clay soils (Kadambi 1972). Teak requires relatively large amounts of calcium for its growth and development. Also soil pH is another factor limiting the distribution and stand development of the species, the optimum pH range for better growth and quality is between 6.5-7.5 (Seth and Yadav 1959; Kaosa-ard 1981; Tewari 1992). Teak can grow naturally over a wide range of climatic condition, but annual rainfall is required between 1,200 and 2,500 mm with a dry season of 3-5 months, for high quality wood production with optimum growth (Kaosa-ard 1981; Keogh 1987).

Sukchan and Sakai (2009) classified the soil suited for teak plantation in Udon Thani, Nong Bua Lam Phu and Buri Ram Provinces on the basis of soil properties; sub-soil texture, drainage, soil depth, pH, and fertility, from the soil group map (Land Development Department (LDD) 2004). However, Sukchan and Sakai (2009) showed that some suitability classes were required to be improved after some cross-checks in the field, and the soil suitability classes were recommended to do field checking and reclassifying. Therefore, this study aimed to improve the soil suitability

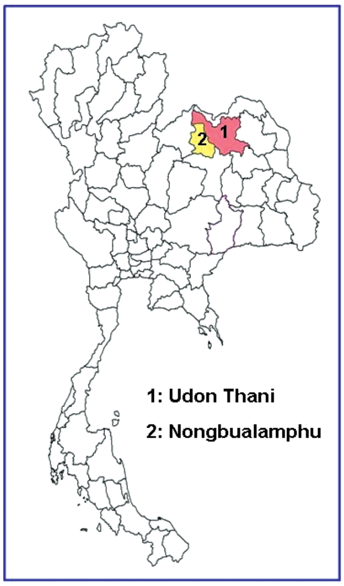

Fig. 1. Location of Udon Thani and Nong Bua Lam Phu Provinces

mapping for teak plantation in northeast Thailand.

Materials and methods

1. Study area

The study areas were Udon Thani and Nong Bua Lam Phu Provinces located in upper northeast of Thailand. Udon Thani Province is located in Khorat Plateau, northeast region of Thailand, between Khon Kaen Province in the south and Nong Khai Province in the north (Fig. 1). The area is 11,730.3 km^2 between N16º 45' – N18º 10' and E 102º 00' – E103º 30'. Mean annual rainfall is approximate 1520 mm and mean annual temperature is 26.1ºC. Three seasons are rainy season (May – October), cold season (November – February), and summer season (March – April). Nong Bua Lam Phu Province is located in the west part of Udon Thani (Fig. 1). The area is 3,859 km² between N16º 43' – N17º 39' and E101º 58' – E102º 42'. Annual rainfall ranges from 1,016 to 1,844 mm (1995-2002), and mean annual temperature is 26.7ºC.

2. Soil in the study area

From soil group map data (1:50,000), The Udon Thani has 33 soil groups and 66 soil groups association (as mapping unit 35/24). The Nong Bua Lam Phu has 20 soil groups and 66 soil groups association. Soil group no. 1 – 13 and no. 59 are low land clayey soil, no.16 – 25 are lowland salty, loamy and sandy soil. Soils are mostly poorly drained. Soil group no. 28 – 31 are upland clayey well drained soil, no. 33 – 38 are upland fine loamy well drained soil, no. 40 – 44 are upland coarse-loamy and sandy well drained soil, no. 45 – 61 are upland shallow soil, no. 54 is upland

Table 1. Soil group properties in Udon Thani and Nong Bua Lam Phu Provinces

Soil group	Subsoil Texture	Drainage	Soil depth	pH	Fertility
1	C	PD	deep	6.0 – 7.5	moderate
2	C	PD	deep	4.5 – 5.5	moderate
3	C	PD	deep	7.5 – 8.0	moderate
4	C	PD	deep	7.0 – 8.0	moderate
6	C	PD	deep	4.5 – 5.5	low
7	C	PD	deep	6.0 – 7.0	moderate
9	C	PD	deep	7.0 – 8.5	low
13	C	PD	deep	7.0 – 8.0	low
16	Sil	PD	deep	5.0 – 6.0	low
17	SCL	SWPD	deep	4.5 – 5.5	low
18	SCL	PD	deep	6.0 – 7.0	low
20	SCL	PD	deep	6.0 – 7.0	low
21	L	MWD	deep	5.5 – 7.0	moderate
22	SL	PD	deep	4.5 – 5.5	low
24	S	SWPD	deep	5.5 – 6.5	low
25	SL/C	SWPD	shallow	4.5 – 5.5	low
28	C	WD	deep	7.0 – 8.0	moderate
29	C	WD	deep	4.5 – 5.5	low
31	C	WD	deep	5.5 – 6.5	moderate
33	Si/L	WD	deep	5.5 – 6.5	moderate
35	SCL	WD	deep	4.5 – 5.5	low
36	CL	WD	deep	6.0 – 7.5	low
38	L	WD	deep	5.0 – 7.0	moderate
40	SL	WD	deep	4.5 – 5.5	low
41	LS	WD	deep	4.5 – 5.5	low
43	S	WD	deep	5.5 – 7.0	low
44	LS	WD	deep	5.5 – 7.0	low
45	gC	WD	shallow	4.5 – 5.5	low
46	gC	WD	shallow	5.5 – 6.5	low
47	gC	WD	shallow	5.0 – 7.0	low
48	gSL	WD	shallow	5.0 – 6.0	low
49	gC	MWD	shallow	5.0 – 6.5	low
54	C	WD	moderate	8.0 – 8.5	moderate
56	gSL	WD	moderate	5.0 – 6.0	low
59	C	PD	deep	5.0 – 6.0	low
60	LS	WD	deep	5.0 – 6.0	low
61	Sl	WD	shallow	4.5 – 5.5	low
62	-	-	-	-	-

Remarks) Subsoil texture is shown as C : Clay, SiL : Silt Loam, CL : Clay Loam, SCL: Sandy Clay Loam, SL : Sandy Loam, LS : Loamy Sand, gC : gravelly Clay, gSL : Gravelly Sandy Loam. Drainage is shown as PD: Poorly Drained, SWPD : Some What Poorly Drained, WD: Well Drained, MWD: Moderately Well Drained.

alkaline soil and no. 62 is mountainous areas. The details of each soil group are in Table 1.

3. Methods

We collected the data of soil group map and soil suitability map for teak plantation in Udon Thani and Nong Bua Lam Phu Provinces, and also collected the teak plantation sites position data from Royal Forest Department (RFD). The soil suitability maps (Sukchan and Sakai 2009) were overlaid with teak plantation sites for selecting observation plantations. In field observations at teak plantations, we observed teak growth class by dominant tree height and trees stem features. We collected three soil samples per site by depth using an auger. The field observations were done in rainy season (July and August, 2010) at 29 sites. We observed the landform and soil properties to describe actual soil features of limitations, and reclassified the relationship between the actual soil features and teak growth class to revise the soil suitability. The revised soil suitability classes for teak plantation from soil groups were mapped for Udon Thani and Nong Bua Lam Phu Provinces. Finally, the accuracy was investigated by comparing the revised soil suitability class by the field observation with the actual teak growth class.

Result and discussion

1. Reclassification of soil suitability classes for teak plantation

Due to lack of information for soil suitability of teak plantation in Udon Thani, Sukchan and Sakai (2009) applied for teak plantation, the set of soil suitability classification which LDD (1990) had made from other economic crop trees information and information on soil survey. The soil properties which were considered for soil suitability were subsoil texture, drainage, soil depth, soil pH and natural soil fertilities. Sukchan and Sakai (2009) classified the soil suitability into three classes as well suited, moderately suited, and unsuited. However, from our field surveys in Udon Thani, Nong Bua Lam Phu and Loei Provinces, we found that soil suitability classes should be extended from three classes to five classes for better estimation as follows;

1: Soil very well suited,
2: Soil well suited,
3: Soil moderately suited,
4: Soil poorly suited,
5: Soil unsuited.

The soil suitability class was denoted with the rank of classes and the limitation of soil, according to LDD (1990). We used the limitations of LDD (1990) in the same way as Sukchan and Sakai (2009);

a : slightly acid,
d : drainage problem or too wet,
f : flood problem,
g : gravel mixed in soil or shallow soil,
n : nutrient status,
s : soil texture is not suited as very sandy soil or low natural fertilities.

The limitation shows inadequate feature up until next superior soil suitability class. For example, 2n means that the soil suitability class could advance to the 1st class, if the soil didn't have nutrient status problem.

In the field, we evaluated a teak growth class as an expert score of a survey team (1 : very good, 2 : good, 3 : moderate, 4 : poor and 5 : very poor). We revised the old suitability three classes; 1, 1a, 2d, 2g, 2s, 3d, 3g, 3f, SC, W, with five classes. Each class of soil suitability was set to correspond to two classes of the teak growth. Relationship between the revised soil suitability class and teak growth class was set as Table 2. No soil group accounts for mountain area of SC and water body of W, because soil group data was historically made for cash crops cultivation on agricultural lands.

Table 2. Relationship between the revised suitability class and teak growth class

Revised soil suitability class	Teak growth class	Remarks
1	1-2	
2n	2-3	
3d	3-4	
3g	3-4	
3s	3-4	
4d	4-5	
4g	4-5	
5f	5	
SC	-	Mountain area
W	-	Water body

The representative soil series for each soil suitability class in Udon Thani, Nong Bua Lam Phu Provinces were as follows;

1 : very well suited soil, representative soil series were Loei series (Lo), Wanghi series (Wi), Chieng Mai series (Cm), Tha Muang series (Tm), Si khu series (Si),
2n : well suited soil, but soil pH slightly low for teak; representative soil series were Korat series (Kt), Satuk series (Suk),Warin series (Wn), Yasothon series (Yt), Pakchong series (Pc), Chokchai series (Ci),
3s : moderately suited soil with limitation that soil texture was not suited as very sandy soil or low natural fertilities; representative soil series were Chum Puang series (Cpg), Chakkarat series(Ckr), Ban Phai series (Bpi), Mahasakham series (Msk), Nampong series (Ng),
3g : moderate suited soil with limitation of gravel mixed soil or shallow soil in; representative soil series are Chieng Khan series (Ch), Phon Pisai series (Pp), Sakon series (Sk), Phon Ngam series (Png), Lat Ya series (Ly),
4g : poor suited soil with limitation of bedrock or thick gravel mixed in soil; representative soil series were Tha Yang series (Ty), Mae Rim series (Mr),
4d : poor suited soil with limitation of drainage or wet for teak; representative soil series were Ubon series (Ub), Phen series (Pn),
5f : non suited soil with limitation of flooding; representative soil series were Buri Ram series (Br), Pimai series (Pm), Ratchaburi series (Rb), Chum Saeng series (Cs), Nakhorn Panom series (Nn), Roi Et series (Re), Renu series (Rn), Kula Ronghi series (Ki), Udon series (Ud) (LDD 2004).

The legend of soil suitability class followed the association system the same as soil group map. The legend of soil group map is sometimes built up with association of the soil groups (LDD 1990). For example, the associated soil groups 31/49 means soil group 31 associated with 49. It means they can't separate to single unit due to the limitation of map scale etc., but the front soil group 31 is dominant.

Table 3. Area of soil suitability classes for teak plantation in Udon Thani Province

Revised soil suitability class	Area (ha)	%	Remark
1	5,853	0.5	21,009 ha
1/3g	14,825	1.4	1.9%
1/3s	10	0.0	
1/4g	321	0.0	
2n	36,552	3.3	132,005 ha
2n/3g	8,347	0.8	12.1%
2n/3s	86,603	7.9	
2n/4g	93	0.0	
2n/5f	410	0.0	
3g	234,090	21.4	462,086 ha
3s	213,609	19.6	42.3%
3s/3g	11,358	1.0	
3s/4g	3,029	0.3	
4d	60,385	5.5	130,443 ha
4d/3g	33,366	3.1	12.0%
4g	36,682	3.4	
5f	247,524	22.7	257,626 ha
5f/2n	728	0.1	23.6%
5f/3g	2,223	0.2	
5f/3s	7,151	0.7	
SC	12,254	1.1	Mountain area
W	76,059	7.0	Water body
Total	1,091,475	100.0	

Table 4. Area of soil suitability classes for teak plantation in Nong Bua Lam Phu Province

Revised soil suitablility class	Area (ha)	%	Remark
1	2,689	0.7	7,816 ha
1/3g	5,127	1.3	1.9%
2n	13,272	3.3	77,316 ha
2n/3g	35,061	8.7	19.1%
2n/3s	26,376	6.5	
2n/4g	2,607	0.6	
3g	23,001	5.7	66,392 ha
3g/4g	16,575	4.1	16.4%
3s	19,445	4.8	
3s/3g	5,171	1.3	
3s/4g	2,200	0.5	
4d	2,441	0.6	85,754 ha
4d/2g	473	0.1	21.2%
4d/3g	50,986	12.6	
4g	31,854	7.9	
5f	98,383	24.3	118,046 ha
5f/2n	5,860	1.4	29.1%
5f/3g	543	0.1	
5f/3s	12,218	3.0	
5f/4d	1,042	0.3	
SC	40,719	10.0	Mountain area
W	9,270	2.3	Water body
Total	405,311	100.0	

We interpreted that the soil group 31 and 49 were related to the soil suitability class 1 and 3g, respectively. Therefore, the soil suitability 1/3g meant the association of two classes, and the class 1 was dominant.

2. Mapping of soil suitability class for teak plantation

As for Udon Thani Province, the results showed very well suited areas were 21,009 ha (1.9 %) in the northwest part of Province as Na Yung and Nam Som Districts (Table 3). Well suited areas were 132,005 ha (12.1 %) mainly in Kudchab, Nong Wua So, Nong Saeng and Wang Sam Mo Districts. Moderate suited areas were 462,086 ha (42.3 %). Poorly suited areas were 130,443 ha (12.0 %) and unsuited areas were 257,626 ha (23.6 %) as detail in Table 3 and Fig. 2. Mountain area and water body were 1.1 % and 7.0 %, respectively.

As for Nong Bua Lam Phu Province, the results showed very well suited areas were 7,816 ha (1.9 %) in the northwest part of the Province as Suwan Khuha District (Table 4). Well suited areas were 77,316 ha (19.1 %) mainly in Na Klang, Si Bun Ruang and Mueang Districts. Moderately suited areas were 66,392 ha (16.4 %). Poorly suited areas were 85,754 ha (21.2 %), and unsuited areas were 118,046 ha (29.1 %) as detail in Table 4 and Fig. 3. Mountain area and water body were 10.0 % and 2.3 %, respectively. In general, teak can grow better on slope area than flat area. Therefore, the mountain area must be potentially suitable for teal plantations, and Nong Bua Lam Phu was supposed to be higher ration of soil suited soil classes than the Udon Thani, if we involve the mountain area.

3. Accuracy test of soil suitability for teak plantation

We compared the revised soil suitability class with actual teak growth class (Table 5). The revised soil suitability class was evaluated by the field observation. The result of comparison showed that 20 sites were accord (69 %), five sites were underestimated (17 %) and four sites were overestimated (14 %). The detail of comparisons was shown in Table 3. From interviews with farmers, teak plantations managed with watering or fertilizing etc. showed better teak growth class than the revised soil suitability. Therefore, the teak management was supposed to be an important factor which affected to raise teak growth class than corresponding to the soil suitability class.

Conclusion

The soil suitability classes for teak plantation in northeast Thailand were classified into five classes as soil

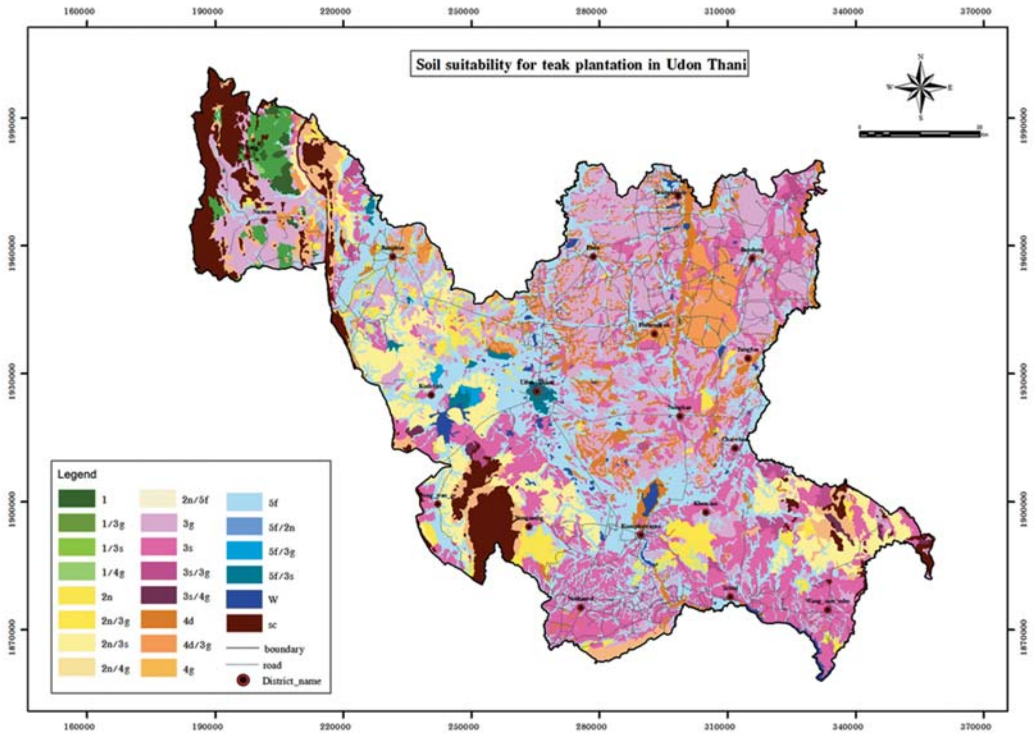

Fig. 2. Revised soil suitability map for teak plantation in Udon Thani Province

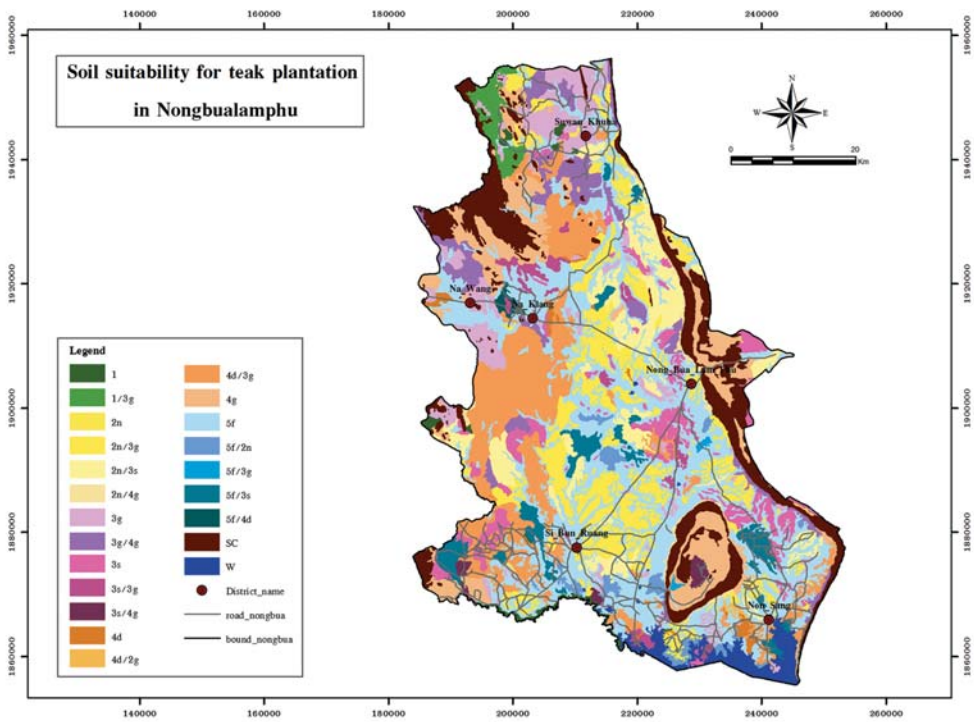

Fig. 3. Revised soil suitability map for teak plantation in Nong Bua Lam Phu Province

Table 5. The comparisons of the revised soil suitability class with actual teak growth classes

No.	Observed sitecode	Revised soil suitability class	Actual teak growth class	Result of comparison
1	NS1	1	1-2	accord
2	NS2	3g	2-3	accord
3	NS3	3g	2-2.5	underestimated
4	NS4	3g/4d	4	accord
5	NS5	3g	2-2.5	underestimated
6	NS6	3g	3-3.5	accord
7	NS7	3g	3.5-4	accord
8	NY1	SC	1-2	accord
9	NY2	1/3g	2-2.5	accord
10	NY3	1/3g	3	accord
11	NY4	3g	3-3.5	accord
12	NS9	3g	3.5-4	accord
13	BP1/1	4d/3g	4.5-5	accord
14	BP2	2n/3g	1-2	accord
15	Nbm5	2n	3.5	overestimated
16	Nbm6	2n	4	overestimated
17	Nbm7	5f	3-4	underestimated
18	Nbm8	5f	2-2.5	underestimated
19	Nbm4	3s/3g	5	overestimated
20	Nbm3	3s/3g	4	accord
21	Nbm2	5f	4.5-5	accord
22	Nbm1	2n/3s	5	overestimated
23	Nb s1	1/3g	1-1.5	accord
24	Nb s2	1/3g	2	accord
25	Nb s3	1/3g	3-4	accord
26	Nb n1	4d/3g	3	accord
27	Nb n2	4g	4	accord
28	Nb n3	5f/4d	4	accord
29	Nb n4	5f/4d	1	underestimated

very well suited, soil well suited, soil moderately suited, soil poorly suited and soil unsuited. We conducted the map accuracy test by the comparisons of the revised soil suitability with teak growth class. As the result, 69 % was accord, 17% was underestimated, and 14% was overestimated.

This study selected two Provinces in upper parts of northeast Thailand. The areas were not the representative of whole northeast. Also teak plantation management was supposed to be a significant factor affecting on teak growth with the exception of the revised soil suitability class. Another study should be conducted to survey and take samples from middle and south parts of northeast for more complete conclusion covering the whole northeast region.

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Variable density yield model for teak plantations in the Northeast of Thailand

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Abstract

Variable density yield model for teak plantations in the northeast of Thailand was developed based on 85 temporary sample plots located in the 7 provinces of the northeast *i.e.,* Nakhon Ratchasima, Khon Kaen, Sakon Nakhon, Loei, Si Sa Ket, Ubon Ratchathani and Yasothon. The plots ranged in site index from 14 m to 30 m (dominant tree height at 30 years) and were measured for stand growth 1−4 times during the year 2000−2009. All of measurement plots provided 157 data sets for constructing the model.

The estimation data consisted of 36 growth periods of stands ranging in age from 3 to 40 years. Multiple linear regression method was used to simultaneously fit prediction equations for stem volume, stand basal area, stand volume and stand density. An existing Mitscherlich model for dominant height growth fitted with the same estimation data was used to estimate site quality index of the stands. The models were evaluated both quantitatively and qualitatively. Correlation among error components of the prediction equation for stem volume as well as the equations for stand density, stand basal area and stand volume were strong and statistically significant and the mean biases for those estimators were positive. The presented system of models could serve for constructing variable density yield table of teak plantations that required stand level input data.

Keywords: multiple linear regressions, site index, stand density, stand age

Introduction

Teak (*Tectona grandis* L.f.) is the most important indigenous species of Thailand and is one of the most important tropical hardwood species in the international market of high-quality timber. Teak grows well on variety of geological formations and soils, but best on deep, porous, fertile, well drained sandstones with neutral or acid pH (Kadambi 1972).

Preference of teak in soil is relatively fertile with high calcium, phosphorus, potassium, nitrogen and organic matter contents. According to several studies, teak requires relatively large amounts of calcium for its growth and development (Kaosa-ard 1981). Teak may grow from sea level up to 1,200 meters, but the growth is slower on high elevations and on steep slopes (Kadambi 1972).

In 1994, the Royal Forest Department of Thailand (RFD) launched the Economic Forest Plantation Extension Project to promote forest plantation area. The goal was to cover 800,000 ha (5 million rais) and was designed to encourage rural households to plant trees on their lands. Farmers were granted subsidies of 3,000 baht per rai, over 5 years to plant trees, and were allowed to harvest trees after a certain period. This project emphasized to plant indigenous forest tree species. Teak was the most popular one because of its high durability, good dimensional stability and aesthetic qualities made it a very valuable species for forestry plantations. Additionally, the price of teak wood was relatively high due to the increasing demand. Teak was planted all over Thailand under this project around 88,000 ha during 1994-1996, even in the Northeast where natural distribution of this species does not occur. To reach the end target which provided high valuable timber to the owners of teak plantations, understanding growth and yield were essential for them to develop long-term plan for sustainable forest management. Thus information on growth and yield was high priority to distribute.

A yield table is a table showing the expected timber yields by age of an even-aged stand, usually by site index classes, and typically including quadratic mean diameter (D_q), height, number of stems, basal area, and standing volume per unit area; yield tables may also include volume of thinnings, current annual increment (CAI) (The Dictionary of Forestry 2008). There are three types of yield table *i.e.,* normal yield table, empirical yield table and variable density yield table. Normal yield table is a yield table showing the average development of well-stocked stands over time, usually by site index. Empirical yield table is a yield table usually based on inventory data, showing average volumes and other statistics in relation to age and (sometimes) site index classes as they are found in the existing forest. Variable density yield table is a yield table that includes stand density in addition to site index and age as classification or predictor values.

Many investigators had used multiple linear regression techniques to predict growth and/or yield for total stands or for some merchantable portion of stands (e.g. Bennett et al. 1959; Clutter 1963; Sullivan and Clutter 1972; Murphy 1983; Rinehart and Standiford 1983; Burkhart and Sprintz 1984; Borders and Bailey 1986). These models provided growth and yield estimates for the whole stand as a function of stand level attributes such as age, density and site index as well as interaction among these variables. Stand density, in turn might be taken to be a function of an initial measure of stand density, age and site quality. Site quality, expressed by site index, depended on the dominant height in relation to age (Clutter et al. 1983). Clutter (1963) introduced the notion of compatibility in growth and yield equations by recognizing that the algebraic form of the yield model can be derived by mathematical integration of the growth model. Sullivan and Clutter (1972) extended Clutter's model by simultaneously estimating and cumulative growth as a function of initial stand age, initial basal area, site index and future age. Stand-level variables, such as age, site index, basal area, or number of trees per acre, were used to predict some specified aggregate stand volume. No information on volume distribution by size class was provided; thus resultant equations from this approach were sometimes referred to as whole-stand models (Avery and Burkhart 1994).

In July 1992, a yield prediction table was constructed under Reforestation and Extension Project in the Northeast of Thailand, Phase II (REX II) by RFD-JICA in order to predict yield of teak plantations grown in the Northeast of Thailand and then was revised under RFD-JIRCAS project during 2009-2010 after more data in this region was obtained. This type of yield table was identified to empirical yield table that showed average growth and yield data of the forest stand. Regarding the limitation of empirical yield table that could not always provide reliable data, especially data of the old stand, thus the variable density yield table was considered to obtain more reliable data of growth and yield.

The main objective of this study was to develop a system of equations to predict stand growth and yield of teak stands in the Northeast of Thailand using multiple linear regression model as the estimation procedure which was useful to provide essential information for management of farmer teak plantation in the Northeast of Thailand.

Material and Methods

The data were measured in 85 temporary sample plots. Most of the sample plots were established in 2002 by REX II Project and a few plots were established in 2000 by Assessment of the Potentiality of Re-afforestation Activities in Climate Change Mitigation Project to represent most teak plantation sites in the Northeast of Thailand. The plots were located in the 7 provinces of Nakhon Ratchasima, Khon Kaen, Sakon Nakhon, Loei, Si Sa Ket, Ubon Ratchathani and Yasothon. The plots were measured annually for 2-3 years in order to estimate stand growth. The last measurement was conducted during the year 2007-2008, and each plot was measured twice on an average. At each measurement, tree diameter at 1.3 m height from the ground (DBH), tree height and number of survival trees were recorded. The stem volume of individual tree was computed using the formula developed by Ishibashi et al. (2002):

$$V = 0.000100712\, DBH^{1.89445042}\, H^{0.763796917} \quad (R^2 = 0.98) \qquad (1)$$

where V is individual stem volume (m^3), DBH is diameter at 1.3 m height from the ground (cm) and H is tree height (m).

Stand growth parameters (number of trees, average height, average DBH, dominant tree height, stem volume and stand volume) for each plot were calculated. Site index was determined from the dominant tree height and age of each plot, using the dominant tree height growth model developed by Ishibashi et al. (2010). This model used Mitscherlich curve as a guide curve of height-growth:

$$DTH_{gt} = 31.755015621\, [1 - 0.772111113 \exp(-0.027606608\, t)] \quad (R^2 = 0.64) \qquad (2)$$

where t is stand age (year) and DTH_{gt} is dominant tree height at age t on the guide curve (m).

The average height of each plot (Hm) could be estimated by the dominant tree height at measurement time (DTH)

$$Hm = 0.976\, DTH - 2.5243 \quad (R^2 = 0.97) \qquad (3)$$

(Ishibashi et al. 2010).

1. System of equations

Several basal area and volume prediction models as well as prediction of number of trees (survival trees) were fitted to the data using multiple linear regression model. The best model (equation) was determined by coefficient of determination, residual analysis and biological implication. The simultaneous system of prediction equations consisted of stand basal area, stem volume, stand volume and stand density as shown in the form of multiple linear model:

$$\text{Ln}\, Y = \alpha + \beta_0 \text{Ln} X_1 + \beta_1 \text{Ln} X_2 + \beta_2 \text{Ln}\, X_3 + \ldots + \beta_n \text{Ln}\, X_n \qquad (4)$$

where Y is a variable such as stem volume (m^3/tree), stand volume (m^3/ha), stand basal area (m^2/ha), stand density (trees/ha) (survival at measurement time) and average *DBH* (cm), X_1, X_2, X_3…, X_n are stand growth parameters such as stand volume, stand basal area etc., Ln is natural logarithm, α, β_0, β_1, β_2 are unknown parameters to be estimated from the data.

Site index was defined as dominant tree height at the base age. Since the rotation age is often used as the base age, therefore 30 years was adopted as the base age. Since the use of the system of the equation required the estimation of dominant tree height of each plot at measurement time, therefore estimated dominant tree height was computed by the following equation :

$$DTH_t = SI\left(\frac{DTH_{gt}}{DTH_{g30}}\right) \quad (5)$$

where SI is site index value (m), DTH_t is estimated dominant tree height at age t (m), DTH_{gt} is dominant tree height at age t on the guide curve (m) and DTH_{g30} is dominant tree height at age 30 years old on the guide curve.

When DTH_{gt} and DTH_{g30} were substituted in Eq.5, DTH_t could be estimated by Eq. 6: -

$$DTH_t = SI\,\frac{31.755015621\{1-0.772111113\exp(-0.027606608\times t)\}}{31.755015621\{1-0.772111113\exp(-0.027606608\times 30)\}} \quad (6)$$

Site index curve were produced by Eq. 6 under the range of SI from 14 to 30 (Fig. 1).

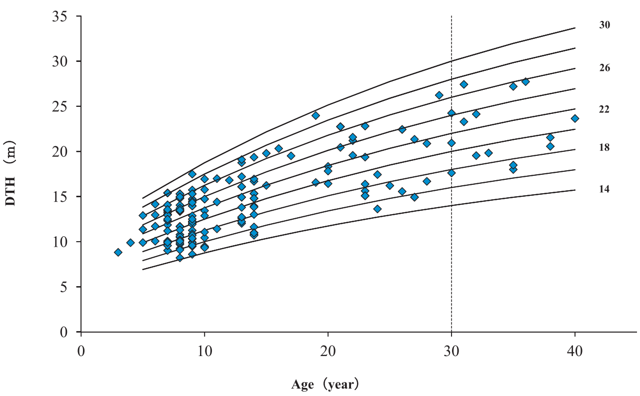

Fig. 1. Site index curve used in this study

2. Model evaluation

The model was evaluated quantitatively and qualitatively using all data for fitting the model. Quantitative evaluation was based on ordinary residuals and the prediction ability of the models was evaluated based on the basis of prediction residuals.

3. Fitting statistics

Quantitative evaluation involved the characterization of model error (bias and precision) and model efficiency (coefficient of determination, R^2). In addition, residuals were examined to detect any obvious pattern and systematic discrepancies. Model bias and precision were evaluated by computing the mean residuals (MRES), the root mean square error (RMSE) and the absolute mean residuals (AMRES) (Eq. 7, 9, and 11). These were also expressed in relative term as percentage of predicted mean value (Eq. 8, 10 and 12).

$$\text{MRES} = \frac{\Sigma\,(y_i - \hat{y}_i)}{n} \quad (7)$$

$$\text{MRES\%} = 100\frac{\Sigma\,(y_i - \hat{y}_i)\,/\,n}{\Sigma\hat{y}_i\,/\,n} \quad (8)$$

$$\text{RMSE} = \sqrt{\frac{\Sigma\,(y_i - \hat{y}_i)^2}{n-1}} \quad (9)$$

$$\text{RMSE\%} = 100\sqrt{\frac{\Sigma\,(y_i - \hat{y}_i)^2/(n-1)}{\Sigma\hat{y}_i\,/\,n}} \quad (10)$$

$$\text{AMRES} = \frac{\Sigma\,|\,y_i - \hat{y}_i\,|}{n} \quad (11)$$

$$\text{AMRES\%} = 100\frac{\Sigma\,|\,y_i - \hat{y}_i\,|\,/n}{\Sigma\hat{y}_i\,/\,n} \quad (12)$$

where n is number of observations and y and $\hat{y}$ are observed and predicted value respectively.

The bias and precision of the prediction models of the system were also examined using different intervals of age class.

Using data sets from 85 independent sample units the goodness-of-fit for all sub-models was also conducted using a bilateral paired t-test. It was used to perform a pair-wise comparison between the observed value and the predicted value computed by the sub-models. The null hypothesis was that there was no significant difference between the actual values and the predicted values. The difference between those values was evaluated to show that whether there is statistically significant difference or not.

The stand volume of different initial-density stands was qualitatively examined by using 45-degrees line test. Since most of teak plantations in Thailand were raised using 4x4m, 2x4m and 2x2m spacing (the initial densities were 625,1250 and 2,500 trees/ha respectively) those three initial stand-densities were selected. The observed values and the predicted values were plotted to examine the trend of the slope of expected curves. If the expected curves tend to make an angle of 45 degrees with the axes, this meant that there was no significant difference between the actual values and the predicted values.

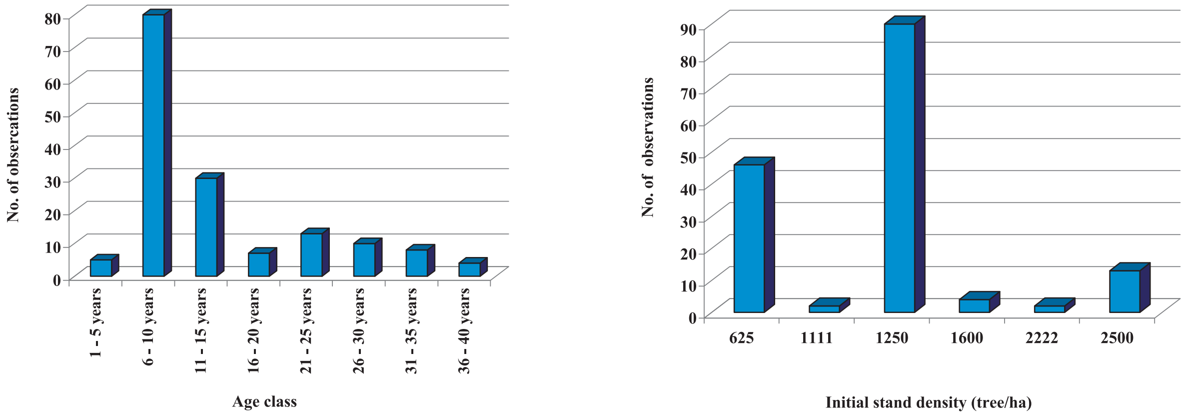

Fig. 2. The characteristics of the 85 temporary sample plots

Table 1. Summary of the characteristics of the 85 temporary plots, as computed from the 157 observations used in the study

Variable	Average (min, max)	SD
Stand age (yr)	14.0 (3, 40)	8.6
Site index (m)	21.0 (14, 29)	3.7
Stand basal area (m^2/ha)	10.9 (3.4, 29.3)	5.3
Stand density (tree/ha)	893.0 (188, 2450)	439.6
Dominant tree height (m)	15.0 (8, 28)	4.4
Stand volume (m^3/ha)	81.0 (17, 268)	54.7
Frequency of measurement per plot	1.9 (1, 4)	1.3

Results and Discussion

The characteristics of 157 observations as derived from the 85 temporary sample plots used in the study shown in Table 1.

The stand characteristics were given for the measurement time of the sample plots. Both of the observations covered various initial densities, however most of them existed on 625 trees/ha (4x4m spacing), 1,250 trees/ha (2x4m spacing) and 2,500 trees/ha (2x2m spacing). Most of stand age ranged from 6-15 years old accounted for 54% of all data sets (Fig. 2). It should be made aware of the restrictions of our data, having a small number of the observations over 30 years old and less than 5 years old of stand age. The number of sample plots which initial stand densities were 1,111 trees/ha and 2,222 trees/ha was very few.

The average DBH of each stand was computed using multiple linear regression model:

$$\text{Ln } DBH = 1.3566 - 0.1704 \text{Ln } I - \text{Ln } 1/A + 0.7877 \text{Ln } Hm \quad (R^2 = 0.96) \qquad (13)$$

where I is initial stand density (trees/ha), $1/A$ is inverse age (1/year), Hm is average height growth (m) and Ln is natural logarithm.

Table 2. Parameter estimates and their standard errors for the sub-models

Dependent variable (Y)	Parameter	Estimate	Standard error
Vt	α	-11.1761	0.5600
(stem volume, m^3/tree)	β_0	-0.4421	0.0580
	β_1	-1.3977	0.0436
	β_2	2.7502	0.0987
V	α	-7.3040	0.6446
(stand volume, m^3/ha)	β_0	0.3123	0.6670
	β_1	0.9543	0.0502
	β_2	2.2898	0.1136
Ba	α	-6.4560	0.6443
(stand basal area, m^2/ha)	B_0	0.3353	0.0667
	β_1	-0.6860	0.0502
	β_2	1.5440	0.1136
N	α	3.8722	6.2073
(stand density, tree/ha)	β_0	0.7544	11.6857
	β_1	0.4434	9.1211
	β_2	-0.4603	-4.1872

Table 3. Cross-equation correlation matrix of residuals of the equations system

	V	*N*	*Vt*	*Ba*
V	1.0000	*0.4976*	*0.3903*	*0.9451*
N		1.0000	*-0.1849*	*0.5903*
Vt			1.0000	*0.2321*
Ba				1.0000

Italic type (significant at $p < 0.05$)

The yield prediction sub-models were derived for stem volume (m^3/tree), stand volume (m^3/ha), or stand basal area (m^2/ha) or stand density (trees/ha). Various parameters of stand growth were chosen to fit the sub-models. It was found that the appropriate independent variables of the sub-model were the natural logarithm of initial stand density,

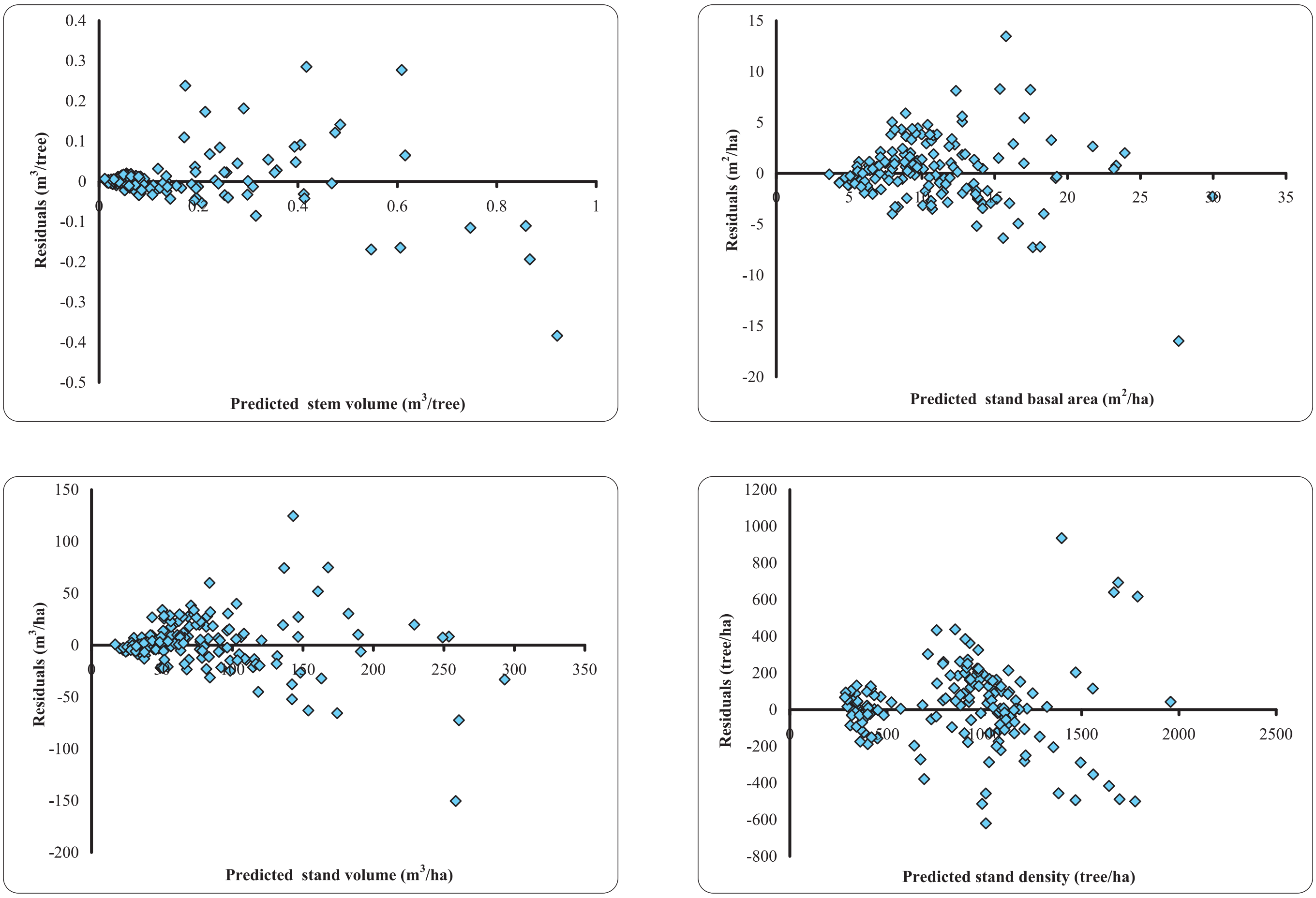

Fig. 3. Residual versus predicted values for the sub-models of stem volume, stand volume, stand basal area and stand density

Table 4. Characterization of error for Multiple Linear Regression Equations

	R^2	MRES	MRES%	AMRES	AMRES%	RMSE	RMSE%
V	0.85	1.6736	2.10	16.7799	21.05	2.1388	2.68
Vt	0.96	0.0030	2.05	0.0303	20.59	0.0053	3.57
Ba	0.72	0.2918	2.76	2.1694	20.51	0.2549	2.41
N	0.81	22.2881	2.56	151.0032	17.33	2.0170	2.02

inverse age and site index value and the dependent variables were the natural logarithm of the above stand aggregates:

$$\text{Ln}\, Y = \alpha + \beta_0 \text{Ln} I + \beta_1 \text{Ln} 1/A + \beta_2 \text{Ln} SI \quad (14)$$

where Y is a variable, such as stem volume (m^3/tree), stand volume (m^3/ha), stand basal area (m^2/ha) and stand density (trees/ha) (survival at measurement time), I is initial stand density (trees/ha), $1/A$ is inverse age (1/years), SI is site index value (m) and Ln is natural logarithm.

The parameters estimates of the sub-models (Eq. 14) as well as their associated standard error were shown in Table 2. The coefficient of determination (R^2) of all sub-models was quite high. All parameters estimates were logical and significant at 0.01 level. Correlation among error components for stand volume, stand density, stem volume and stand basal area were significant at 0.05 level (Table 3). A negative cross-equation correlation of residuals between the stem volume and stand density at the same age means that if the stem volume is overpredicted, it is likely that the stand density is underpredicted.

This study presented stand-level growth and yield models for teak plantations in the Northeast of Thailand. The sub-models for stem volume, stand volume, stand basal area and stand density were fitted simultaneously using multiple linear regression, while the dominant tree height growth model developed by Ishibashi et al. (2010) was used independently to predict dominant tree height of teak stand.

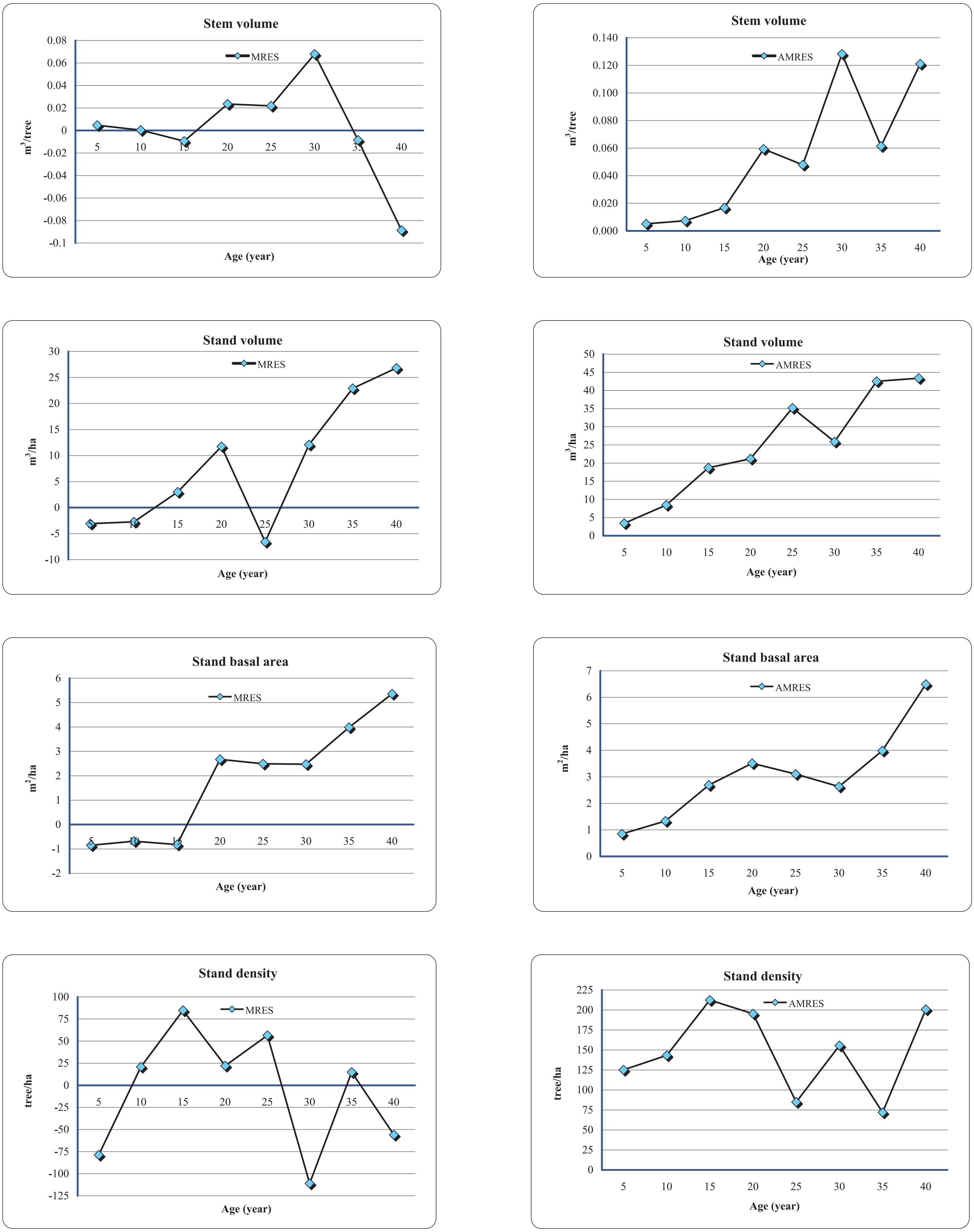

Fig. 4. MRES (model bias) and AMRES (model precision) for the prediction sub-models of stem volume, stand volume, stand basal area and stand density

Table 5. The results of paired sample *t* - test of the yield prediction

	t - value	*p* - value
V	0.7865	0.4327^{ns}
Vt	0.5759	0.5655^{ns}
Ba	1.1531	0.2506^{ns}
N	1.2792	0.2027^{ns}

Significant level ($p < 0.05$), ns : not statistically significant.

Since the dominant tree height derived the system of the yield model and it was also used to estimate the site index of a given stand, it had to be assured that a robust and reliable prediction model for dominant tree height was available.

There were no serious patterns on the distribution of residuals in the stem volume, stand basal area, stand volume and stand density (Fig. 3).

MRESs were positive for all multiple linear regression equations (sub-models) of the stem volume, stand basal area, stand volume and stand density (Table 4), showing that some positive bias exists in the model. MRES%s and MRESs as well as RMSE%s and RMSEs which measured bias, were quite small. This meant that the sub-models provided accurate prediction. On the contrary, AMRES%s and AMRESs which measured precision, were rather large around 17%-20% for all sub-models.

Fig. 4 showed the bias (MRES) and precision (AMRES) by each of the prediction sub-models of the system using different predictions intervals. The predictive ability of all sub-models decreased as the stand age increased.

The bias in stem volume, stand volume and stand basal area from 5 years to 15 years of interval were smaller than the longer interval which meant that the sub-models gave more accuracy for 5-15 year-old stands than the older stand. The stand density sub-model provided accurate prediction for 10, 20 and 35 years of interval.

The AMRESs in stem volume, stand volume and stand basal area from 5 years to 15 years of interval were smaller than those of longer interval which meant that the sub-models gave more precision for 5-15 year-old stands than the older stand. The stand density sub-model gave more precision for 5, 10, 25 and 35 years of interval than other intervals of ages. It could be concluded that the stem volume, stand volume and stand basal area sub-models gave more prediction ability for 5-15 year-old stands than the older stand.

The predicted stand volume was underestimated when the stand was approximately 5, 10 and 25 years old, while it gave overestimate when the stand was approximately 15, 20, 30, 35 and 40 years. The prediction ability in the stand volume showed smallest when the stand was 40 years old.

For a more statistically comparison in the goodness-of-fit of all sub-models, the observed values of all sample plots were collectively compared with the corresponding values

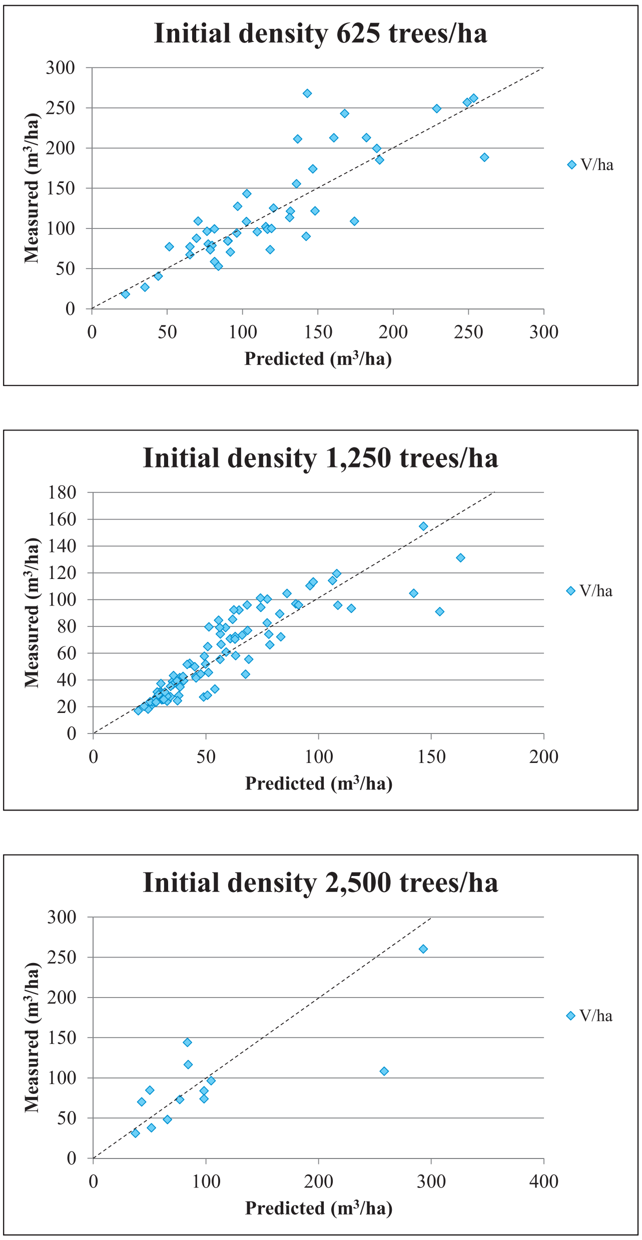

Fig. 5. Comparison of the 45 degree line test

predicted by the yield prediction equations. The comparisons were made with the help of paired sample t-test. These implied that the observed values of all predictions (stem volume, stand volume, stand basal area and stand density) were not significantly different from those predicted values at 0.05 level (Table 5). Thus the system of yield prediction model was acceptable.

Using graphical method, the model was also qualitatively evaluated by comparison of stand volume among the various initial stand densities. Fig. 5 showed the relationship between actual (measured) value and predicted value of stand volume. The trend of the slope of expected curves compared among different initial stand densities (625, 1,250 and 2,500 trees/ha) was less different from 45 degrees line. It can be observed that the models tended to make an angle of 45 degrees with the axes, meaning that there was no significant difference between the actual yield and the predicted yield. The model tended to give both overestimation and underestimation of the actual yields for each initial-density stand.

The construction of variable density yield table was based on the set of models developed in this study and on the dominant tree height growth model developed by Ishibashi et. al. (2010). The yield table was constructed through the following steps:

1. For each stand, compute the dominant tree height by using Eq. 2 and compute the site index value by using Eq. 6.
2. Compute the average tree height from the dominant tree height by using Eq. 3.
3. Predict the average diameter of the stand at the prediction age by using Eq.13.
4. Predict stem volume, stand volume, stand basal area (Eq.14) based on initial stand density, inverse stand age (stand age at prediction time) and site index value.

Conclusion

The variable density yield model developed in this study could be implied to construct the yield prediction table for teak plantation in the Northeast of Thailand after the confirmation of the sub-models through the validity test. Although the developed model showed a high reliability of prediction ability, it had certain limitations for the system of equations used in this model. It should only be used for predicting growth and yield of teak stand in the Northeast of Thailand where all of data were collected. The application of the model must be in the range of these data. In addition, the use of the model was also based on age limitations. The results from validity test confirmed that the accuracy and precision of the model were best for the stand age ranged from 5-15 year-old. If the stand age was beyond this range, the predicted values were likely to have more bias and inconsistency.

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Current situation and solution on management of Nong Bua Lam Phu Private Forest Plantation Cooperative Limited

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Abstract

This study aimed to examine the current situation in the cooperative management of Nong Bua Lam Phu Private Forest Plantation Cooperative Limited and to provide recommendations for strengthening the management. The study was conducted by interviewing the opinions of chairman and committee members of the cooperative on the advantages and disadvantages in the current management situation. The study found that most of committee members agreed that the current organization had sufficient and appropriate committee members. The existing products were easy to distribute to customers based on their orders. The committee members were also satisfied with their knowledge of plantation management, cooperative management and operational readiness. Members also had knowledge of plantation and cooperative management and always participated in the meetings and distribution of the cooperative's products. Moreover, the cooperative had database of the members' plantations, good markets and low competition were advantages as well. However, there were several disadvantages of the organization such as low incentive, short supply of raw materials, outdated equipments and lack of working capital and insufficient loans due to no land as an asset for guarantee. Changes in social could result in labor shortages; however, the local government policy had no impact on cooperative operations.

In conclusion, there were five strategies to strengthen the cooperative management. First, the cooperative administrative office should be managed by a professional manager, accounting and marketing officers. Second, the cooperative should serve as a distributor of log, timber and members' wood products. Third, members should produce teak products by themselves including for solving the lacking of carpenters. Forth, the cooperative should give opportunity for the local labor to participate as an employee. Finally, Royal Forest Department should review and edit the rules and regulations of teak plantation for increasing plantation area and promoting the utilization of teak in the future.

Keywords: Nong Bua Lam Phu Private Forest Plantation Cooperative Limited, situation, solution, management

Introduction

Forest Plantation Cooperative is a project initiated by the Royal Forest Department (RFD) with a strong commitment to adding value to wood originated from retail private forest plantations by means of setting up a market center of logs and sawn timbers, wood processing plants i.e. wood production factory, sawmill and etc. for making furniture, charcoal, handicrafts, inventions, tools and utensils, which helps assure retail private entities especially forest growers of market availability.

In order to achieve the goal shown the foregoing paragraph, forest farmers nationwide were encouraged to meet and discuss about an idea to form a private forest plantation cooperative. On 20 October 1995, the said assembly resolved to form a private forest plantation cooperative named "Private Forest Plantation Cooperative Limited", by assigning Mr. Prajam Sukkaew, a farmer in Nakornsawan as the team leader to apply for registration under the Cooperatives Act, B.E. 2511 (A.D. 1968). The registration was done on 8 March 1996, under cooperative registration number 0054399, in the category of agricultural cooperative (RFD 1998). The preliminary office was situated at 61 Paholyothin Road, Chatuchak, Bangkok (temporary use), with the aim of administering cooperatives in every province where forest affairs were operated. As a rule, each cooperative has 15 committees, and its objectives are 1) to encourage the unification of forest plantation owners and set up a private forest plantation cooperative at the local level. A brainstorming session must be held to thrash out various issues such as productivity and fund management, etc. 2) to be an institution for developing and promoting collaborative efforts and close rapport among members, helping one another, by adhering to fundamental human morality and good ethics. 3) to make private forest plantations successful, promote forest farming on a continuous and integrated basis, solve the shortage of utility wood, and to tackle environmental impacts and 4) to solve socio-economic problems aimed at enhancing the well-being and living conditions of people, by making forest farming a sustainable career for farmers to do for living.

Although the purpose of establishing forest plantation cooperatives in Thailand is to get rid of forest-farming problems in the private sector, there are many disadvantages and obstacles to overcome i.e. lengthy time to obtain yields, the unavailability of wood markets, exploitation from middlemen, and excessive bureaucracy or adherence to rules and formalities (red tape). Moreover, not many forest growers were members of forest plantation cooperatives due to several constraints such as their limited knowledge and understanding of cooperative principles, and the socio-economic conditions of the target group, and so on. The number of private forest plantation cooperatives has shown a decline against the preliminary goal to have cooperative businesses in every province where forest affairs were operated. The numbers of private forest plantation cooperatives declined, from 36 provinces in 2002 to 31 provinces in 2009 (30 forest plantation cooperatives and 1 service cooperative). It can be inferred that the administration of forest plantation cooperatives in Thailand does not have much success as it should.

In the northeast of Thailand, there were a lot of farmers who were interested in farm forestry. However, an effort to encourage farmers to plant trees still lacks clear goals about marketing and on how to utilize small wood. It is, therefore, necessary to support and strengthen the administration of forest plantation cooperatives to make farmers feel confident about their investment in forest farming. This study aimed to examine the current situation in the cooperative management of Nong Bua Lam Phu Private Forest Plantation Cooperative Limited and to provide recommendations for strengthening the management to attain its strengths and fulfill its formation objectives.

Materials and methods

This study was conducted at Nong Bua Lam Phu Private Forest Plantation Cooperative Limited, Nong Bua Lam Phu Province in the northeast of Thailand. This Private Forest Plantation Cooperative Limited is an organization registered on 30 March 2000 as a juristic person under the Cooperatives Act B.E. 2542 (A.D. 1999), with 75 original members. 90 % of planted species was teak, the total planting area was 2,080 ha (13,000 rai), and 80 % of members was low-income farmers. Current operations or activities are 1) furniture factory, using small-size teak as raw material. 2) the sales of wood products and furniture items. 3) the purchase of logs from farmers (both members and non-members), the purchase price will be determined by the board, by considering reference price data obtained from RFD and the Forest Industry Organization (FIO) and 4) giving help to members in various matters such as an application for RFD's permission for teak felling and shipments, forest plantation management technique, the sale of teak to middlemen, the sending of members for training or study tours at many different agencies, and the dissemination of log price information obtained from RFD (Reforestation Promotion Office, RFD 2005).

All of the thirteen committee members of Nong Bua Lam Phu Private Forest Plantation Cooperative Limited were interviewed about the current management situation such as organization, management and ability of committee and member etc. The gathered information of their opinions were interpreted and were divided into advantages and disadvantages. Then, we considered the strategies to strengthen the management of Nong Bua Lam Phu Private Forest Plantation Cooperative Limited.

Results and discussion

1. Current situation in the cooperative management

(1) Organization

About 80 % of committee members agreed that the current organization has sufficient members and about 70 % agreed that committee members are appropriate in term of mission and knowledge. While the Private Forest Plantation Cooperative Limited had low incentives, the committee members worked as volunteers. So they interpreted that this is disadvantage issue (Table 1).

Table 1. Disadvantages and advantages of Nong Bua Lam Phu Private Forest Plantation Cooperative Limited in organization issues

Items	Disadvantage		Advantage	
	Number	%	Number	%
1. Number of committees	2	15.4	11	84.6
2. Mission	4	30.8	9	69.2
3. Knowledge	4	30.8	9	69.2
4. Incentive	10	76.9	3	23.1

(2) Management

The study found that the existing products are easy to distribute to customers based on their orders, 100 % thought that customers need and selling products are the advantages of management. There were several disadvantages of management such as short supply of raw materials, the outdated equipments. Some committee members thought that because patterns follow the on demand products, it is the advantages. While others thought that few and limited

Table 2. Disadvantages and advantages of Nong Bua Lam Phu Private Forest Plantation Cooperative Limited in management issues

Items	Null		Disadvantage		Advantage	
	Number	%	Number	%	Number	%
1. Material finding	0	0.0	11	84.6	2	15.4
2. Producing	0	0.0	9	69.2	4	30.8
3. Pattern of products	0	0.0	6	46.2	7	53.9
4. Customer need	0	0.0	1	7.7	12	92.3
5. Selling product	0	0.0	0	0.0	13	100.0
6. Finance	0	0.0	9	69.2	4	30.8
7. Loan	1	7.7	10	76.9	2	15.4

Table 3. Disadvantages and advantages of Nong Bua Lam Phu Private Forest Plantation Cooperative Limited in committee member issues

Items	Disadvantage		Advantage	
	Number	%	Number	%
1. Cooperative knowledge	1	7.7	12	92.3
2. Plantation management knowledge	0	0.0	13	100.0
3. Price assessment	0	0.0	13	100.0
4. Product selling	0	0.0	13	100.0
5. Meeting	1	7.7	12	92.3
6. Law and regulation understanding	0	0.0	13	100.0
7. Recommendation to members	0	0.0	13	100.0

Table 4. Disadvantages and advantages of Nong Bua Lam Phu Private Forest Plantation Cooperative Limited in constituent member issues

Items	Disadvantage		Advantage	
	Number	%	Number	%
1. Cooperative Knowledge	6	46.2	7	53.9
2. Plantation management Knowledge	4	30.8	9	69.2
3. Price assessment	9	69.2	4	30.8
4. Product selling	2	15.4	11	84.6
5. Meeting	0	0.0	13	100.0

pattern are disadvantages. In addition, lacking of working capital and insufficient loans due to no land as an asset for guarantee were also disadvantages of management (Table 2).

(3) Committee members

The committee members were satisfied with their knowledge of plantation and cooperative management, product selling, including price assessment, recommendation to members. They were also satisfied with their understanding in law and regulation of RFD (Table 3).

(4) Members

Committee members though that Private Forest Plantation Cooperative Limited's constituent members also have knowledge of plantation and cooperative management. The constituent members helped to distribute the cooperative's products and especially always participated in the meetings (Table 4).

(5) Other issues

The opinion of committee members to other issues found that;

1) The cooperative has database of the members' plantation such as species, area and location. Even though, less update data when member harvested their trees. And the cooperative did not have information about tree stock or volume of their members.
2) The sufficient instrument and technology, good markets, and low competition in teak products are advantages.
3) There are 53.9 % of committees felt that changing in social can result in labor shortage, while 30.8 % said that the social does not impact to the cooperative management.
4) 53.9% of committees felt advantage in RFD law and regulation. 46.2 % of committees felt the disadvantage,

Table 5. Disadvantages and advantages of Nong Bua Lam Phu Private Forest Plantation Cooperative Limited in other issues

Items	Null		Disadvantage		Advantage	
	Number	%	Number	%	Number	%
1. Database of member	0	0.0	1	7.7	12	92.3
2. Government policy	7	53.9	5	38.5	1	7.7
3. RFD law and regulation	0	0.0	6	46.2	7	53.9
4. Wood market	0	0.0	3	23.1	10	76.9
5. Tool, instrument and technology	0	0.0	5	38.5	8	61.5
6. Social changing	4	30.8	7	53.9	2	15.4
7. Competitor	0	0.0	4	30.8	9	69.2

they mentioned about the problem due to the officers. However, the local government policy had no impact on cooperative operations (Table 5).

2. Recommendations for strengthening the management

Himmapan et al. (2010) studied the administration and operations of various cooperatives on forest plantations such as Maha Sarakham, Lop Buri, Kanchanaburi Private Forest Plantation Cooperatives Limited etc. The advantages were shown as followings;

1) The present activities were not only produce wood furniture, but also consisted of the purchase of logs from members at better prices than anywhere, logging from members' forest plantations, log sale, and furniture making.
2) The organizational and administrative structure of the committee was clear.
3) The product items were supplied by a member and sale by cooperative.
4) There were some positions working in the cooperative are the professional people.

(1) Strategies for strengthening the management

From the disadvantage issues or problems and obstacles of the administration and operations of Nong Bua Lam Phu Private Forest Plantation Cooperative Limited, in comparison with other forest-related cooperatives, the following five strategies could be recommended to strengthen the cooperative management in future.

1) The cooperative suffered loss in the early years, no dividend was paid. However, the cooperative recently began to make profit and was able to pay dividends to members in 2008. The financial situation has recently been better, but not stable. The Private Forest Plantation Cooperative Limited is managed by committee members who are farmers. The results showed that most of them were lack of the management and business knowledge. Therefore, the cooperative administrative office was recommended to be managed by a professional manager, accounting and marketing officers.
2) The current activities were only sale of wood products and furniture items, while it was facing short supply of raw materials and the outdated equipments. The cooperative should serve as a distributor of log, timber and members' wood products.
3) The problem on lacking of the skill carpenters, members should produce teak products by themselves. They can get income and solve problems of lacking carpenters.
4) The cooperative should give opportunity for the local labor to participate as an employee. Not only solving the lack of the carpenters, but the cooperative also supported the social and economic of their community.
5) Finally, Royal Forest Department should review and edit the rules and regulations of teak plantation for both cutting red tapped by amending official rules and procedures that are practically difficult, unnecessary, or unfavorable to the felling, shipment, manufacturing and sale of teak logs or teak products and increasing plantation area and promoting the utilization of teak in the future.

(2) Expectations of assistance from RFD

1) Strengthen cooperative operations by the provision of training programs on workmanship/craftsmanship development, creative product design, and effective administrative management.
2) Raise funds to support ongoing management and maintenance of farmers' forest plantations, build motivation for farmers who want to conduct commercial thinning for a better future of their forest plantations and for raw material continuous supply to cooperatives' factories.
3) Improve systems with regard to license application and approval procedures to facilitate the operations of teak growers and entrepreneurs.
4) Coordinate with other agencies in both public and private sectors to find teak markets for cooperatives.
5) The objectives of the formation of forest-related cooperatives were the unification to build a group's strengths, enhance the quality of life, and promote the well-being of forest growers and forest-related entrepreneurs, as well as to increase the area of forest plantations for the country. So, regardless of whether cooperatives are under the supervision of RFD or Cooperative Promotion Department, RFD should remain in charge of monitoring, coordinating and supporting cooperative activities on a continuous basis to reinforce

the potential of forest-related cooperatives.

Conclusion

The study found that most of committee members agreed that the current organization has sufficient and appropriate committee members. The existing products were easy to distribute to customers based on their orders. The committee members were also satisfied with their knowledge of plantation management, cooperative management and operational readiness. Members also had knowledge of plantation and cooperative management and always participated in the meetings and distribution of the cooperative's products. Moreover, the cooperative had database of the members' plantations, good markets and low competition were advantages as well. However, there were several disadvantages of the organization such as low incentive, short supply of raw materials, outdated equipments and lack of working capital and insufficient loans due to no land as an asset for guarantee. Changes in social could result in labor shortages; however, the local government policy had no impact on cooperative operations.

There were five strategies to strengthen the cooperative management. First, the cooperative administrative office should be managed by professional. Second, the cooperative should serve as a distributor of log, timber and members' wood products. Third, members should produce teak products by themselves. Forth, the cooperative should give opportunity for the local labor to participate as an employee. Finally, RFD should review and edit the rules and regulations of teak plantation for increasing plantation area and promoting the utilization of teak in the future.

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Current functions and expected roles of Private Forest Plantation Cooperatives in Thailand

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Abstract

In Thailand, large areas of private tree plantations were established by the Economic Tree Plantation Promotion Project initiated by Royal Forest Department (RFD) since 1994. To secure the profits from these tree plantations, Private Forest Plantation Cooperatives (PFPC) have been set up all over the country since 1996. As a result, a total of 36 Private Forest Plantation Cooperatives had been established by 2002. The current functions and expected roles of PFPC were investigated on the basis of interviews with the board members of PFPCs. The results showed that the current functions and expected roles of PFPCs differed from place by place according to regional properties, such as the existence of a local market for teak and the abundance of resources. Some key points for the future development of PFPCs were considered to be planning of development that fits the local needs and constraints, strengthening of organization and appropriate role sharing among board members, and consideration of the sustainability of activities based on updated forest resource information.

Keywords: Private Forest Plantation Cooperative, Teak (*Tectona grandis*), Tree planting promotion, Farm forestry, Thailand

Introduction

In Thailand, forest areas declined drastically from 53.3% in 1961 to 25.3% in 1998 (RFD 2008). Legal and illegal logging and land conversion from forests to agricultural land are the main causes of deforestation (Mahannop 2004; Sharp and Nakagoshi 2006). The Royal Forest Department (RFD) initiated several policies and projects to oppose this one-sided conversion by promoting private plantations around the beginning of 1990. The office of Private Reforestation and Extension was set up in the RFD in 1986 and the Forest Plantation Act was endorsed in 1992. Two important projects supporting private sector involvement in tree plantation development were initiated in 1994 (Mahannop 2004). Among these, the Economic Tree Plantation Promotion Project was one of the most influential projects initiated by the government. This project provided a subsidy (3,000 baht/rai (1 rai=0.16 ha), equivalent to US$750/ha in 1994) to people who planted economic tree species on their land over the initial 5 years (Sharp and Nakagoshi 2006). The project was implemented from 1994 to 2002. A total of around 390,000 hectares were planted by local people under the project (RFD 2002).

Teak (*Tectona grandis*) has been one of the most important and valuable tree species in Thailand with a long history of plantation started in 1906. Therefore, many participants chose teak as the tree species to plant under the project (Sharp and Nakagoshi 2006). More than 15 years have passed since the project started. Teak trees in the first generation of the project have grown to reach the minimum merchantable size (Kijkar 2001). Therefore, some harvesting of teak for sale came to be observed in local areas. At the same time, some planters converted their tree plantations back into agricultural land or other types of plantation when they lacked sufficient information or a clear vision on the future returns of their tree plantations. It is reported that many planters were unwilling to sell their trees to buyers or middlemen at an unreasonably low price (Noda et al. 2011). Under these circumstances, it is important to organize groups such as cooperatives or associations to secure planters' profits while attaining independence of individual planters and achieving fair trade.

In Thailand, Private Forest Plantation Cooperatives

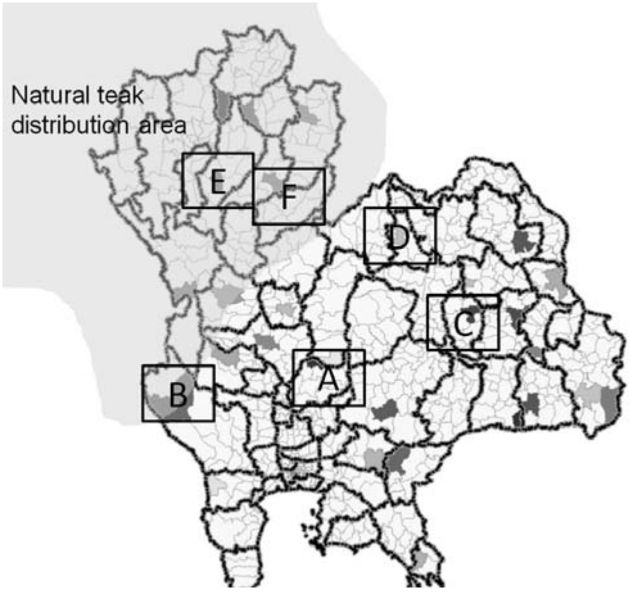

Fig. 1. Distribution of the established PFPCs (their locations are shaded) and the surveyed PFPCs and SCs (shown by letters) (A: Lop Buri PFPC, B: Kanchanaburi PFPC, C: Maha Sarakham PFPC, D: Nong Bua Lam Phu PFPC, E: Lampang Handicraft Cooperative, F: Don Moon Wood Product Service Cooperative). This map was drawn on the basis of documents from the Private Plantation Division of RFD. The distribution of teak natural stands was sketched with reference to Gyi and Tint 1998.

(PFPCs) started to be set up by the RFD in 1996. A total of 36 PFPCs had been established by 2002. However, the total number of PFPCs had declined to 30 by 2009. This shows that PFPCs did not always work as well in Thailand as they should (ITTO 2006; Himmapan et al. 2010). There were some studies on the factors affecting the planters' decisions upon participation in a PFPC (e.g. Saengpan 2003; Laowphaphao 2005). However, there have been quite a limited number of studies directly focusing on the activities of PFPCs.

Therefore, the objective of this study was to elucidate the current functions and expected roles of PFPC through comparative case studies on organization and activities in order to find out the keys for developing PFPCs in Thailand.

Materials and Method

Interviews with the board members of selected PFPCs and related Service Cooperatives (SCs) were conducted in December 2009. Candidate cooperatives that cover the whole of Thailand, except for the southern part, were sampled. The six sampled provinces were Lop Buri, Kanchanaburi, Maha Sarakham, Nong Bua Lam Phu, Lampang and Phrae (Fig. 1). Items on which questions were asked were organization of cooperatives, current activities, future plans and surrounding conditions. Firstly, the current functions and the expected roles of PFPCs in Thailand were investigated referring to actual activities and good practices. Then, on the basis of the earlier observations on current situations, the obstacles and expectations for PFPCs were discussed.

Results

The current status and activity of surveyed PFPCs were summarized in Table 1. All these PFPCs were established around the year 2000, but the current functions of PFPC differed from place by place according to regional properties. Operation of Lampang PFPC in the north of the country was not successful and cancelled. Therefore, the activities of Lampang Handicraft Cooperative and Don Moon Wood Product Service Cooperative in Phrae were only mentioned in the text.

Hereinafter, the results of interview on current functioning, successful practices and expected roles of PFPC were described in detail.

1. Securing and expanding the teak wood market

There was a teak market in the northern part and eastern part of the country because there used to be teak wood processing factories and also a high demand in the central region near Bangkok. However, in the northeast of Thailand, there was a limited demand for teak because local factories were not used to dealing with it. Therefore, the PFPC itself was expected to provide a market for teak logs by running a sawmill and/or a furniture factory. Nong Bua Lam Phu PFPC has been running a furniture factory to process doors and window frames by order (Fig. 2). Maha Sarakham PFPC also has been buying teak logs from its members and has been running a factory to process them, although its main material was eucalyptus wood. Lop Buri PFPC in the central part of the country also has been buying teak logs from its members at a higher price than others and processing these at a variety of processing stages, such as log, sawn timber, and furniture, making use of the advantage that it was located near Bangkok and also near the wood processing factories surrounding Bangkok.

2. Sharing knowledge and techniques

The Economic Tree Plantation Promotion Project was initiated to promote tree planting by the private sector in Thailand (Mahannop 2004). Technical assistance was needed because planters usually did not have much experience or knowledge about silvicultural activity. It was also pointed out that buyers set a low price upon trading in teak directly with farmers (Noda et al. 2011). Therefore, not only technical assistance in terms of silvicultural techniques but also support and the provision of knowledge on socio-economic aspects were needed. The private plantation promotion division of the RFD has been providing seminars

Table 1. Current status and activity of surveyed PFPCs and regional characteristics

Location	Code Region Cooperative	A Central Lop Buri	B Central Kanchanaburi	C Northeast Maha Sarakham	D Northeast Nong Bua Lam Phu
Establishment		2000	1998	1997	2000
Regional characteristics	Distance to Bangkok	○	△	△	×
	Distance to North	×	×	×	△
	Local market	×	○	×	×
	Low land competition	○	△	×	×
Activity	Current activity	○	×	○	○
	Factory	○	×	△	○
	Technical consultation	○	×	○	○
	Technical seminar	○	○	○	○
	Production of seedlings	×	×	○	×
	Planting (contract work)	×	×	○	×
	Logging (contract work)	△	×	○	△
	Support for permission	○	×	○	○
	Networking	○	△	○	○
	Promotion	△	△	△	△
	Money lending	×	○	×	×
Remarks		Selling logs, sawntimber, furniture Strong hope for log auction market	Many members or planters operate small wood processing factory Money lending	Main activity is on eucalyptus wood and charcoal making Good dividend	Selling furniture by order

The marks in the table show the positive (○), negative (x), moderate (△) evaluation given by the author subjectively based on the interviews. Locations of the PFPCs are shown in Fig. 1.

Fig. 2. Photograph of the furniture factory operated by the Nong Bua Lam Phu PFPC

related to the management of teak plantations and periodically also providing information on the price of wood to the PFPCs. Participants in seminars were often chosen from the members of the PFPCs. The PFPCs often referred to the provided price table in terms of setting a buying price and in the case of inquiry from their members. PFPCs provided such price lists to their members at annual general meetings. The seminar topics were chosen from among the hot topics. In Kanchanaburi, many participants in a seminar on small log utilization set up small-scale factories individually to process furniture or woodcrafts after attending a seminar. Lop Buri PFPC provided technical seminars on the occasion of their annual general meeting. Voluntary workshops were held at Nong Bua Lam Phu PFPC. Independent developments of PFPCs were ultimately expected. Therefore, the utilization of a variety of occasions for sharing knowledge and techniques among members was highly anticipated.

3. Technical advice and contract work of silvicultural activity

Typical small farm forest planters would experience harvesting for thinning a few times and once at the final cutting. Therefore, it was not easy for individual planters to prepare equipments for harvesting and/or transporting. It was also not so easy for unskilled planters to evaluate their teak stands, which included various sizes of trees. This enabled the middlemen to buy their logs at low prices. Therefore, there was potential for PFPCs to promote fair trade by helping their members to calculate the value of their goods and to support harvesting and transportation, although the validity of the value set by the PFPC should also be assessed separately. At Nong Bua Lam Phu PFPC, one board member collected information on the individuals who wanted to sell their trees and went to calculate teak stand values for members. In the northeast of Thailand, planters did not have enough information on selling trees because the trading of teak was not observed regularly. Lop Buri and Maha Sarakham PFPCs organized a temporary working group to harvest and transport logs using the equipment that they owned. There seemed to be demand for contract work for logging and transportation. Maha Sarakham PFPC even enabled substitute members to plant trees as contract work. Planters were usually not familiar with thinning activity, such as the selection of trees to cut. Therefore, contract work or technical assistance for thinning by a PFPC was considered to have potential to accelerate the implementation of thinning. At present, workers were usually hired occasionally for silvicultural activity. If the number of experienced workers would increase and a sufficient quantity of work be secured, a professional working group may potentially be organized in PFPCs in the future.

4. Support for registration and permission for harvesting and transportation

Harvesting and transportation of teak wood were strictly controlled by the authorities in Thailand. Teak planters had to go to a provincial office to register their tree plantation and to get permission for the logging and transportation of teak. Before the reorganization of the RFD in 2002, there were local staff members at district or sub-district level. Therefore, it was easy for people living in rural areas to contact local officers. Local officers could also easily visit tree plantations for consultations. However, this was now inconvenient for both planters and officers, especially when tree plantations were located far from the office. This was considered to be one factor that prevented planters from implementing thinning. Board members of PFPCs were often elected as a representative to cover the local regions (e.g. district). Therefore, PFPCs may complement the function that the local offices were previously responsible for. In the north or east of Thailand, there was high demand for teak from factories that have been processing wood or making furniture. Therefore, tree cutting and trading has been observed more often in these regions. Planters could easily access information on obtaining permission for their activities locally. Officers were also familiar with the procedures. In addition, buyers could also provide support for the procedures for planters. On the other hand, in the northeast of Thailand, the demand for teak was not so high. Planters in this region lacked experience and knowledge of teak trading and of the procedures for getting permission for their activities. Therefore, PFPCs located in the northeast of Thailand were expected to provide support in the documentation required for permission.

Fig. 3. Photograph of teak processing factory complex managed by Don Moon Wood Product Service Cooperative in Phrae Province

5. Support for permission for processing and selling teak wood

In Thailand, processing and selling or transporting teak wood products were also under the control of the authorities. In particular, it was difficult for an individual to obtain and keep permission for such activities. PFPCs could obtain permission more easily. Making use of this advantage, PFPCs in Nong Bua Lam Phu, Maha Sarakham and Lop Buri run their own factory. Don Moon Wood Product Service Cooperative in Phrae obtained permission, and the members of the cooperative run factories under the one license of the SC. In this case, the SC kept the license to collect rental fees for land and obtained a margin according to the amount of wood processed at each factory. In addition, SC got quotas of teak wood from the local Forest Industry Organization (FIO) to secure raw materials for members (Fig. 3). It would be difficult for an individual to do this, but the existence of a cooperative enabled it.

6. Promotion of wood products

Marketing or promotion of teak wood products was also one of the most important roles for PFPCs in some cases. For example, many members in Kanchanaburi run a small-scale factory. Kanchanaburi PFPC was planning to provide the chance for members to sell and display their products at the shop that one member managed. Selling a variety of products may also lead to more consumers visiting the shop. The promotion of wood products was also important for the PFPCs that run their own factories. Maha Sarakham PFPC displayed its products at its office in the city. Nong Bua Lam Phu PFPC has also discussed the idea of making a showroom, although this has not been realized because the current location of the factory and office of Nong Bua Lam Phu PFPC was far from the city and the main road, and also because the present production level by order was recognized as the current capacity of the PFPC.

7. Money lending

In general, it takes time and money to reach a point where income can be obtained from a tree plantation. Although the efficiency and necessity of thinning have started to be understood gradually, the speed of implementation of thinning was still slow. One of the main activities of agricultural cooperatives in Thailand was financing (Saengpan 2003). Financing was also expected from PFPCs. However, there were only a small number of PFPCs that dealt with financing because of the lack of funding. Among the surveyed PFPCs, only Kanchanaburi PFPC collected funds from the Cooperative Promotion Department at a low interest rate and lent money to its members. Nong Bua Lam Phu PFPC has discussed the possibility of providing funds for its members to conduct thinning and to make members send back the money to the PFPC after selling the thinned trees. Such a short period of financing with a clear objective was considered to be acceptable for the PFPC with a limited budget and weak administration.

8. Networking of information and related institutions

PFPCs were considered to be points that form the basis of a variety of networks. Annual meetings and other meetings promoted the exchange of information and knowledge among the members. Members could ask for assistance on techniques and rules from the board members. Networking between PFPCs themselves was also important. Some PFPCs such as Lop Buri and Nong Bua Lam Phu have accepted study tours from other PFPCs. These PFPCs also planned study tours to other cooperatives and to the northern part of the country where the teak industry has developed. These tours provided new ideas to the members and the board members of PFPCs. PFPCs could also connect members with factories. In some cases, PFPCs provided the information of members who wanted to sell teak to factories as a negotiator. It was also very important to gain confidence among members, PFPCs and the authorities. At present, planters had to register and obtained permission when they cut trees. If a PFPC takes the place of members in obtaining such permission, exchanges between PFPC and the RFD occur more frequently and the confidence between them is considered to grow. There was a possibility that the procedure for obtaining permission might become much smoother than it was at present.

Discussion

1. Relationship between current activity of PFPCs and property of regional forestry

There were differences in the current status of PFPCs according to their region. In the north and west of the country, there was high demand for teak because many teak processing factories have been established there historically. Therefore, there was a market for teak without any support from PFPCs and planters did not expect much from PFPCs. As a result, PFPCs have not been so active in these regions. Instead, service cooperatives were active in securing licenses for processing and selling of teak products and also for securing teak resources as raw materials. On the other hand, it was expected that PFPCs would operate teak processing factories in regions where there was no local market for teak. In Lop Buri, which was close to Bangkok, there were a variety of demands, such as for logs, timber and furniture. As a special case, in Maha Sarakham where eucalyptus plantations prospered, Maha Sarakham PFPC supported teak planters in addition to its main activities with eucalyptus. In this way, the expected functions differed place by place according to the local resources and demand for teak. Therefore, PFPCs should develop with recognition of the regional differences in their expected functions.

2. Strengthening organization and appropriate role sharing

Strengthening the organization of PFPCs was considered to be one of the most important tasks. At present, board members were usually elected as representatives of the local area. The roles of each board member were not always clearly defined. On the other hand, in the example of Kanchanaburi PFPC, board members were elected mainly from the central city. This might enable board members to communicate more frequently; however, it might result in a failure to support or listen to local problems. Alternatively, it has also been pointed out at the interviews that there was a large burden for board members living in rural areas in some cases. These are conflicting issues and have to be settled on the basis of sincere discussions. Leadership of the president or the board members is very important for making PFPCs more active. Good ideas should be provided by the board members. Although the problem that board members could make PFPCs into a private company has been pointed out in some cases, monitoring of PFPCs by their members must be important to prevent this. In Nong Bua Lam Phu PFPC, strengthening of the accounting section contributed to a surplus. It is expected that PFPC activity will be renewed by strengthening and clarification of the roles of board members according to the activities of each cooperative.

3. Consideration of lack of labor and shortage of technical knowledge on silviculture

Planters inevitably grow older, and the youthful laborers in families often move to the cities (Ubukata and Jamroenpruksa 1997). Such aging and family labor shortage was considered to be one of the reasons why planters could not conduct thinning. Therefore, there seems to be a potential demand for contract work on silvicultural activity by PFPCs. It was expected that experienced workers could work as substitutes for members with confidence and at low cost. Lop Buri and Nong Bua Lam Phu PFPCs have already

Fig. 4. Photograph of several sizes of teak logs on sale on the roadside in Lop Buri

hired temporary workers to organize working groups for some silvicultural work such as logging and transportation. Maha Sarakham PFPC conducted planting on the behalf of its members. If the costs of these activities are defined in advance, more investors may be able to make easier calculations and decide to invest in tree planting. In relation to the promotion of thinning, it is important for planters to understand the effectiveness of thinning by watching the growth of stands after thinning with their own eyes. Therefore, it may be an idea to set up demonstration stands of good management supported by PFPCs.

4. Matching the scale of activity at technical, administrative and financial levels of PFPC

PFPC was usually managed by board members who had few skills in business. In this sense, it is one option for PFPCs simply to operate a log auction market if it is difficult for them to manage their own wood processing factories. Log auction markets will connect planters with factories to provide a market. Factories will also be able to access various grades and sizes of logs. One merit of this for planters is that the price will be set appropriately through auctions. However, teak logs have to be transported and stacked at the places where log auctions will be held. These advantages and disadvantages have to be balanced. In interviews, many board members mentioned that it was difficult for PFPCs to prepare the funds to buy logs in advance because planters would need money in advance when they cut trees. For example, in Japan, payment will be made after the auction on the basis of trust between PFPCs and planters. At any rate, financial support for PFPCs should be planned to compensate for the short time lag between harvesting and auctioning. At present, Lop Buri PFPC sells its logs along the roadside (Fig. 4). The high demand for teak logs from factories located in and around Bangkok was considered to be one factor that enabled log selling. Lop Buri PFPC was interested in establishing a log auction market, although one has not been set up yet. As mentioned above, board members of PFPC are not always talented in business like those of a private company. It is thus important at the initial stage for PFPCs to operate a sawmill factory or simply to sell logs to obtain a small amount of profit. Maha Sarakham PFPC expanded its business from a sawmill to a furniture factory step by step, although the main material was eucalyptus. There are various ways for PFPCs to develop; however, as an example, the initial cost of establishing a factory has been a big burden for Nong Bua Lam Phu PFPC because this PFPC has been suffering from a shortage of operational funds as a result of servicing its debts every year. Therefore, one approach is to start with a simple business such as selling logs and sawn timber to obtain profits and then to increase in the scale and quality of the business little by little.

5. Departments in charge of cooperative and forestry policy

In Thailand, there are difficulties in terms of the department in charge of PFPCs between the RFD and the Cooperative Promotion Department. PFPCs needs technical and political assistance from the RFD, but cooperatives are under the control of the Cooperative Promotion Department. The RFD itself does not have a sufficient budget to enable progression of the cooperatives. Therefore, the RFD cannot provide strong financial assistance in terms of technical aspects. Assistance from the RFD was limited to holding meetings at the initial stages. Thereafter, direct support from the RFD was limited to providing the opportunity for members to attend seminars and to providing price information. This difficulty in terms of the departments in charge was considered to be one of the barriers that inhibit the progression of PFPCs.

6. Lack of information on resources and the activity for maintaining sustainability of resources

PFPCs had information on the numbers and areas of members upon their registration, but PFPCs could not update their database in terms of when there was thinning or harvesting. Therefore, the lack of this information made it rather difficult for board members to give consideration on the sustainability for managing resources sustainably. As Maha Sarakham PFPC got support from a provincial office to produce seedlings, those activities for securing future resources should be initiated as one of the important tasks of PFPC.

7. Potential of supporting on teak planters from the organizations operating main profitable activities besides forestry

As they are categorized as special cooperatives, PFPCs conduct specialized work related to tree planting (Saengpan 2003; ITTO 2006). However, if the level of business is insufficient for managing a PFPC, there is another option of larger cooperatives that include most of the planters, such as agricultural cooperatives, giving support to teak management as part of their work. Maha Sarakham PFPC was considered to be one of these cases because the main activity of this PFPC was related to eucalyptus, but it also supported teak planters to make use of its existing organization and networks that were created in association with eucalyptus-related activities.

Acknowledgements

We would like to express our deepest gratitude to the board members of the surveyed PFPC for kindly providing us valuable comments. This study was supported by a joint research project 2006-2010 under RFD and JIRCAS.

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Trends of forestry and wood processing industry in Thailand: Analysis using historical forestry statistics from 1997 to 2008

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Abstract

Trends of forestry and the wood processing industry in Thailand were observed using historical forestry statistics from 1997 to 2008. The deforestation rate slowed down during this period, and land clearing and illegal logging also seemed to be decreasing as a result of forest conservation. Efforts for reforestation by tree planting were also observed, but these did not seem to cause a marked increase in the forested area. Production of rubber sawn wood drastically increased. Pulp production also increased. Rubber plantation areas continued to increase all over the country. Rubber wood was considered to be continuously important as a raw material for the wood processing industry. On the other hand, teak wood was provided mainly from neighboring countries such as Myanmar and Laos. Given that teak wood resources from these countries are decreasing, expansion and supply of domestic teak wood from tree plantations are highly expected. The importance of expansion of widespread data collection on forestry and the wood processing industry should be emphasized for further analysis and planning for the future.

Keywords: wood processing industry, forestry statistics, Thailand, export and import of wood products, teak (*Tectona grandis*)

Introduction

Thailand is located from 2°30' to 20°30'N in latitude and has a variety of climate zones, such as tropical moist climate in the Malay Peninsula, tropical monsoon climate with a long dry season, and relatively cool temperate climate in the north and the west, with mountainous areas. These climates also result in a variety of forest formations, such as tropical evergreen forest, tropical and subtropical montane forest, dry deciduous dipterocarp woodland, and dry deciduous forest (Blasco et al. 1996). Natural teak forests are distributed in the northern and western parts of Thailand along its boundary with Myanmar (Gyi and Tint 1998). Teak woods and teak wood products have been among the main products of Thailand and this region (Gajaseni and Jordan 1990). As the result of the exploitation and the resultant decrease of forest resources, logging ban was declared in 1989. Lakanavichian (2001) discussed the impacts and effectiveness of logging bans on forestry sector in Thailand. Mahannop (2004) also reported the development of forest plantations in Thailand. However, studies on recent trends in Thai forestry and its wood processing industry have been quite limited. Therefore, this study aims to clarify the current situation in the forest and wood industry of Thailand and also to identify its trends over the decade from the end of the 1990s to 2008.

Materials and Method

Thai forestry statistics from 1997 to 2008 were downloaded in the digital format from the website of the Royal Forest Department (RFD). These data were arranged in time series to enable analysis of the transition over time. Some tables were rearranged and recategorized to trace the change in the time series. Some tables disappeared in recent forestry statistics as a result of simplification of the forestry statistics. In such cases, tables were arranged for as long as the data were available in the forestry statistics. Thai words and the English translations were both given in the tables in forestry statistics. However, for example, “Round wood” and “Sawn wood” were used in our study instead of “Log” and “Sawntimber” in forestry statistics. Firstly, basic figures on general forest and forest resources were observed. Then, the transitions of import and export of round wood, sawn wood and wood products were observed. Lastly, on the basis of the above observations, the trends of forestry and the wood industry in Thailand were summarized. The whole of Thailand was divided into 5 regions, namely, Bangkok, Central, North, Northeast, and South.

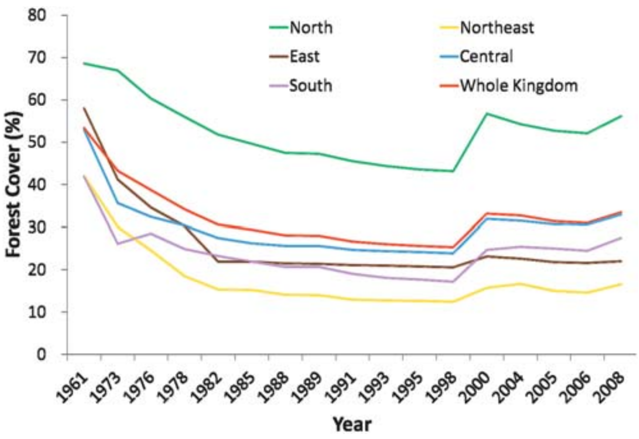

Fig. 1. Transition of forest cover of each region from 1961 to 2008

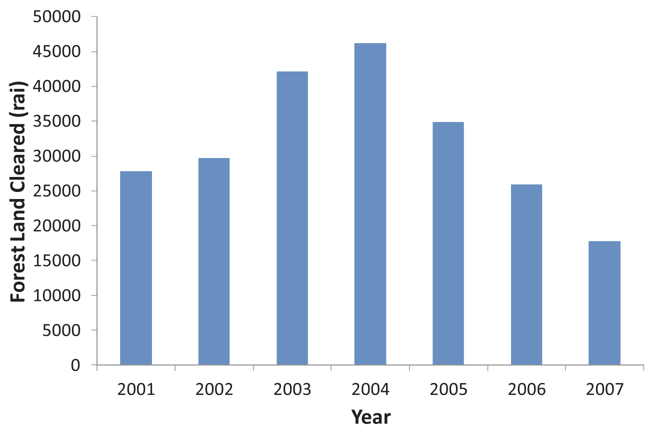

Fig. 2. Transition of areas of cleared forest land from 2001 to 2007

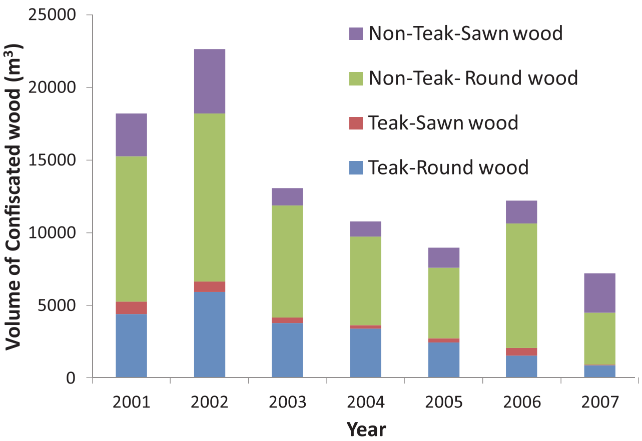

Fig. 3. Transition of volume of wood confiscated from 2001 to 2007

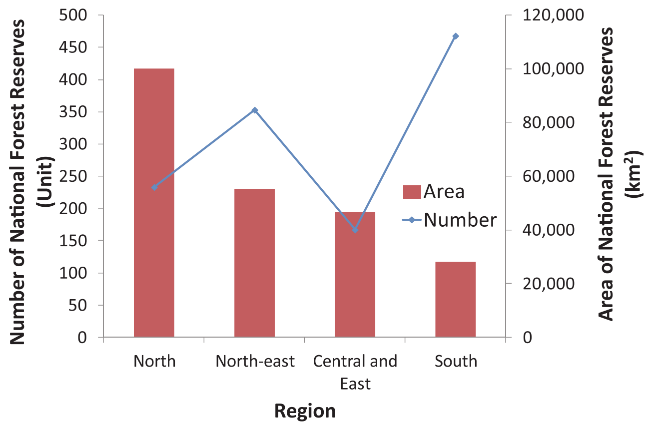

Fig. 4. Numbers and areas of national forest reserves of each region in 2007

Result

1. Transition of general forest resources

1) Transition of forest cover

The transition of forest cover from 1961 to 2008 is shown in Fig. 1. It showed a decline until 1998, but an increase from 2000. This upturn was considered to be caused by a change of the scale of the maps and the methodology as the result of application of new procedure since 2000 (Ongsomwang 2002). Therefore, forest cover change had to be evaluated with care. The rate of forest cover was high in the north, intermediate at around 30% in the south and central regions, and lowest at less than 20% in the northeast. The rate of reduction of forest cover slowed in the 1990s in most areas, but the rate of reduction was still high in the north (0.86% in 1978-88 and 0.43% in 1988-1998). Deforestation also continued in the South (0.42% in 1978-88 and 0.35% in 1988-1998). Focusing on the period after the new method of interpretation was applied, forest cover change has been almost stable and seems even to have slightly increased after 2006.

2) Transition of number of offenses

Cleared forest land peaked in 2004 and decreased thereafter (Fig. 2). The volume of confiscated wood peaked in 2002 and then showed a decline until 2007, although it was high in 2006. The percentage of teak wood as a proportion of the total confiscated wood was high at around thirty percent in the period 2001 to 2005, but became smaller in 2006 and 2007 (Fig. 3). Although the figures are not shown here, the numbers of cases and arrested individuals have decreased since 2001 and the numbers of confiscated machines and pieces of equipment, such as cars and chainsaws, have also decreased (RFD 2005; RFD 2007). These trends may show that rapid deforestation and forest degradation have slowed to a stop in Thailand.

3) Efforts for forest conservation

In Thailand, national parks are managed by the Department of National Parks, Wildlife, and Plant Conservation (DNP), and forest reserves are assigned and

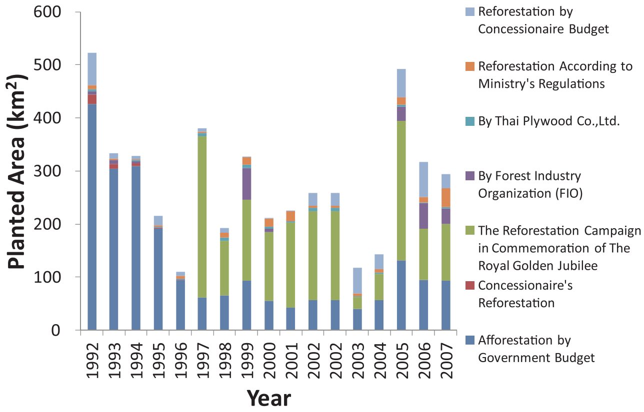

Fig. 5. Transition of planted area through different sources of funding from 1992 to 2007

managed by the RFD to protect and conserve forested areas (FAO 2010). The total area of forest reserves in each region was large in central, north, northeast, and south regions, in that order, and the number of forest reserves was large in south, central, northeast, and north regions, in that order (Fig. 4). Therefore, the average area of forest reserves was large in the north and small in the south, and intermediate in the central and northeast regions.

4) Efforts for reforestation by tree planting budget

As an active effort to increase forested area, reforestation by tree planting was observed to be effective (Fig. 5). However, the total area of reforestation fluctuated year by year and was limited. Tree planting by a reforestation campaign in commemoration of the Royal Golden Jubilee was important after 1997. Reforestation by concessionaire budget was also continuously conducted.

5) Summary of transition of forest resources

The above-mentioned trends of forest resources can be summarized as follows.

1. Forest cover was now rather stable.
2. The amounts of cleared land and confiscated wood were both decreasing.
3. There were some efforts in the assignment of forest reserves and reforestation.

These trends showed that Thailand was emerging from the phase of deforestation and was progressing toward forest conservation. However, strong initiatives for reforestation have not been shown and there was at present no tendency for the recovery of forested areas.

2. Transition of wood processing industry in Thailand

1) Transitions of numbers of wood processing factories and shops in each region and category

The transitions of the numbers of wood processing factories and shops in each category from 1997 to 2008 are shown in Fig. 6. Total numbers were stable to slightly decreasing until 2005 and increased in 2006; they then dropped again but retained the level of 1997. The numbers of wood processing factories and shops showed similar transitions. Regional differences in these transitions were also observed, as shown in Fig. 6. In the north and northeast, the numbers of wood processing factories and shops were stable or slightly decreased until 2005, but increased after 2006. The numbers fluctuated in Bangkok and the south year by year. One of the characteristics in the north and the northeast was that the relative importance of wood processing factories run by manpower, rather than by machines, was high.

The percentages and numbers of wood processing factories and shops in each region are shown in Fig. 7. In the category of sawmills, the percentages of the south and central regions were high. The high percentage in the south was the result of increased numbers of sawmills for processing para rubber wood. In the category of sawmills run by manpower, rather than machines, the percentages in the north and central regions were high. This was caused by the many private teak plantations established in the north and west, and the harvested wood from these plantations was processed at small-scale private factories. The numbers of wood processing factories run with machinery were rather stable, and the percentages in Bangkok and the central region were high during this period. In the category of wood processing factories run by manpower, the percentage in the northeast was high. This showed that small-scale factories were operated in this region. There was no big change in the numbers and regional differences of sawn wood shops and wood product shops during the period. The transitions of numbers of sawn wood shops and wood product shops were synchronized.

2) Current situation of overall import and export of round wood, sawn wood and wood products

The amounts of imported and exported wood and main wood products in 2007 are shown in Table 1. Among the items of imported and exported wood products, the levels of import of round wood, import and export of sawn wood, import of woodchips, export of fiberboard and particle board, export of furniture, import of wood pulp, and import and export of paper were high. The trends of import/export

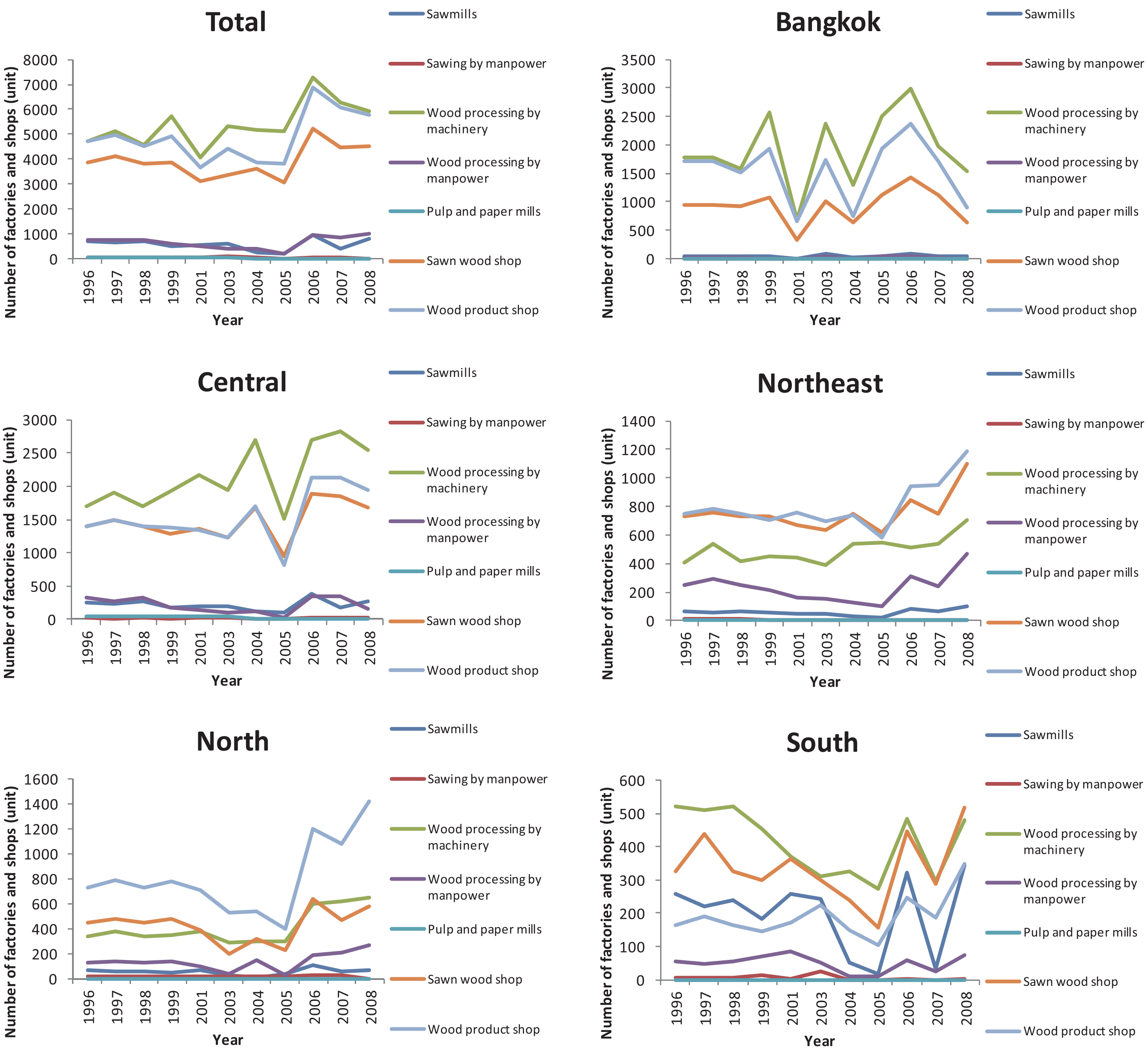

Fig. 6. Transitions of numbers of wood processing factories and shops in each region from 1996 to 2008

of these major types of wood and wood products were investigated in detail hereinafter. To enable the comparison among the different types of products, the recent trends were observed in currency baht. Only the long term trends were observed in volume or weight.

3) Transitions of import and export of round wood and sawn wood

Long term transition of import of round wood and sawn wood from 1978 to 2007 is shown in Fig. 8. Import of round wood and sawn wood increased in the 1990s after the logging ban, and peaked around 1994. It dropped until the Asian economic crisis in 1998, but showed a slight recovery in the early 2000s.

Transition of import of round wood of each tree species from 1995 to 2007 is shown in Fig. 9. Teak was one of the most important tree species in terms of imports in the whole period. The percentage of dipterocarpaceae (*Dipterocarpus alatus* etc.) was large at around 10 to 20% until 2001, but then dropped rapidly. One observed trend is that the percentage of Krabak (*Anisoptera cochinchinensis*), one of the dipterocarpaceae, became relatively high after 2002.

Amount of over half round wood have been imported from Myanmar and Malaysia (Fig. 10). In particular, the percentage of imports from Myanmar was very high at around 60 to 70% in the 2000s. A large amount of teak round wood was imported from Myanmar. On the other

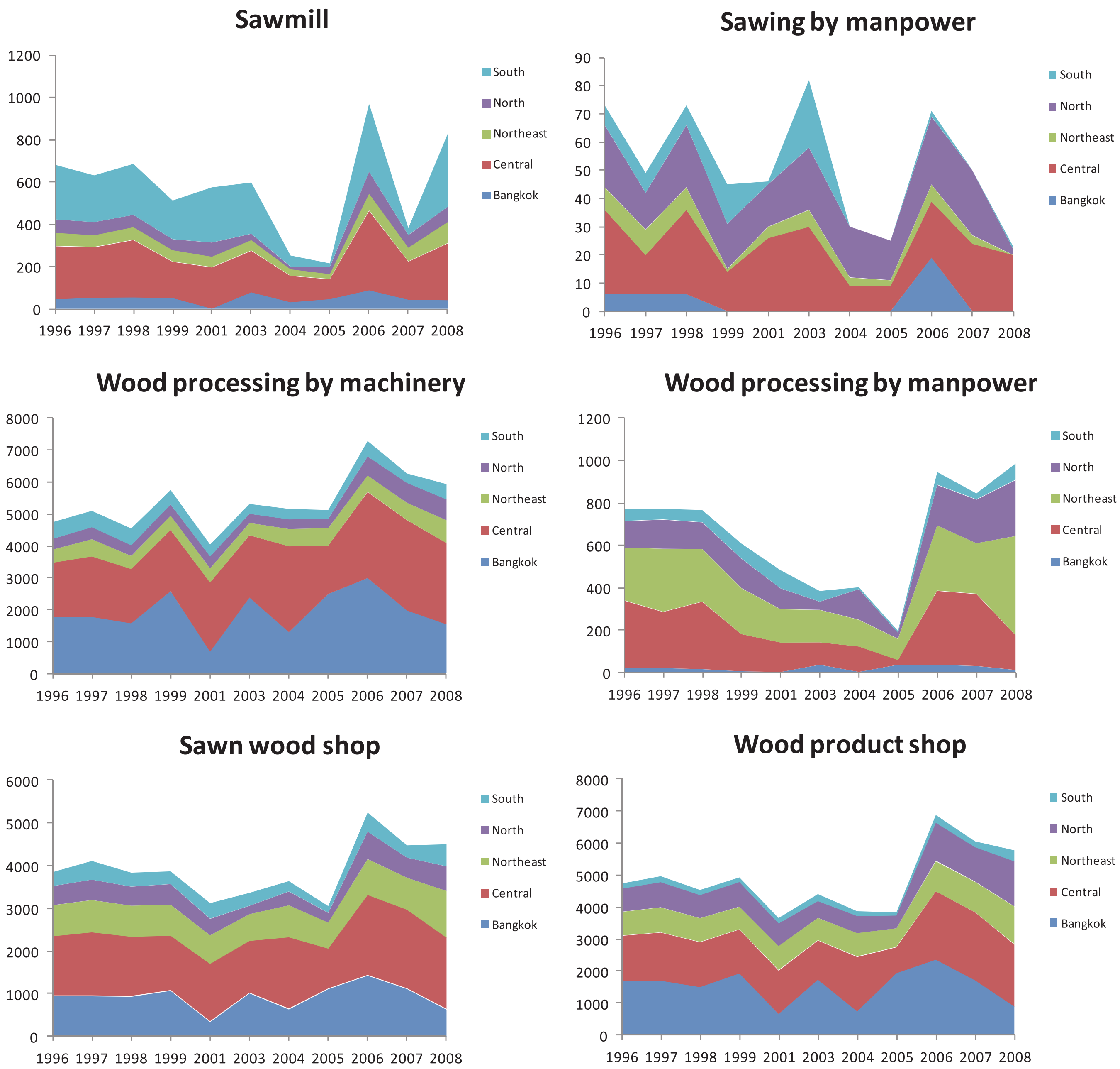

Fig. 7. Transitions of numbers and percentages of wood processing factories and shops in each region and category from 1997 to 2008

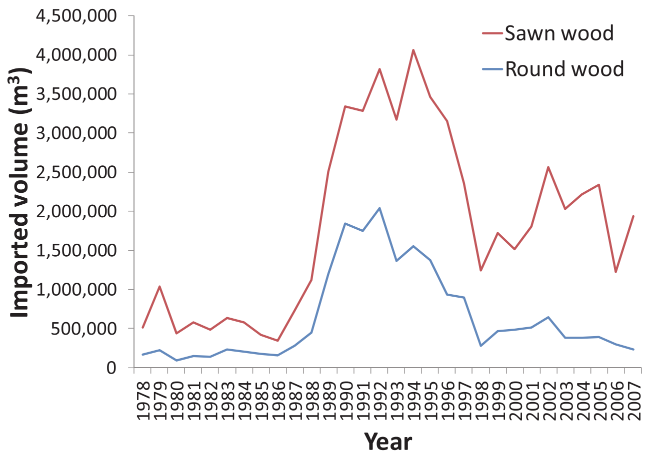

Fig. 8. Transition of imported round wood and sawn wood to Thailand in volume from 1978 to 2007

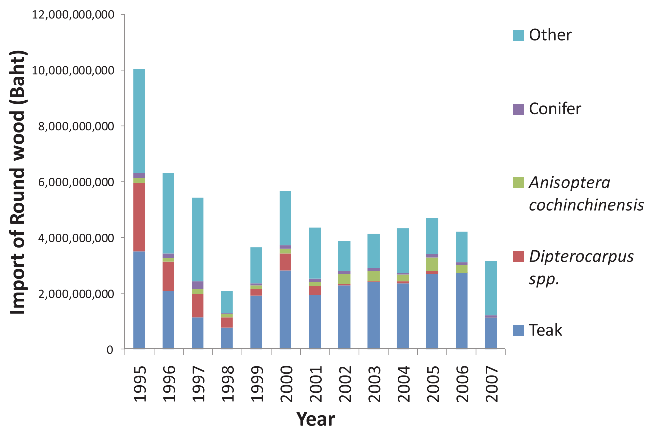

Fig. 9. Transition of imported round wood to Thailand by tree species from 1995 to 2007

Table 1. Levels of import and export of wood and main wood products in 2007

Item	Unit	Import		Export	
		(Quantity)	(Baht)	(Quantity)	(Baht)
Fuelwood	kg	721,029	8,046,769	1,008,752	7,955,072
Wood in chips or particles	kg	754,777	2,938,365	359,436,824	1,025,227,920
Wood Charcoal	kg	40,101,261	124,763,700	39,631,049	72,722,082
Round wood	m^3	231,052	3,166,902,647	5,373	23,084,968
Sawn wood	m^3	1,702,234	12,776,712,327	1,734,571	12,330,539,434
Veneer Sheets	m^3	27,784	814,736,484	1,704	284,183,450
Particle Board	kg	13,761,682	248,863,584	1,110,438,071	8,038,278,789
Fiberboard	kg	26,600,851	508,838,203	678,790,945	7,727,471,875
Plywood	m^3	317,322	2,546,306,026	62,703	784,379,472
Flooring Panels	kg	214,779	12,422,482	541,532	42,669,441
Wooden Furniture	unit	2,448,677	1,021,423,008	24,738,450	17,168,150,692
Other Wood Products	kg	62,128,766	1,380,619,999	110,703,266	10,572,626,498
Wood Pulp	kg	473,010,150	11,934,403,400	212,188,255	4,377,763,651
Other Fiber Pulp	kg	14,827,883	424,081,317	81,089,615	1,438,500,118
Recovered Paper	kg	1,015,931,347	6,458,960,759	13,637,047	147,420,212
Paper and Paperboard	kg	843,371,895	38,165,636,055	1,262,984,348	41,270,678,012

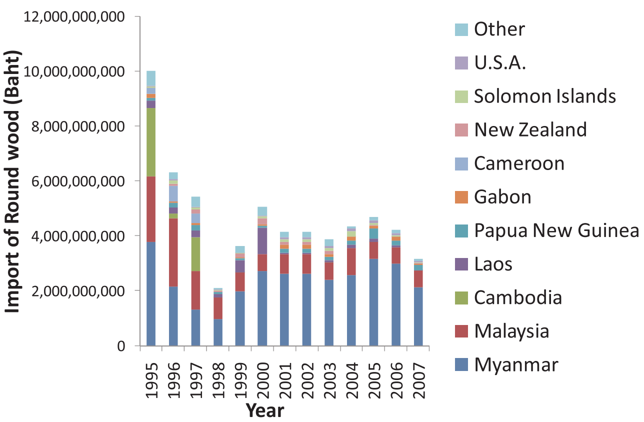

Fig. 10. Transition of imported round wood to Thailand by country of origin from 1995 to 2007

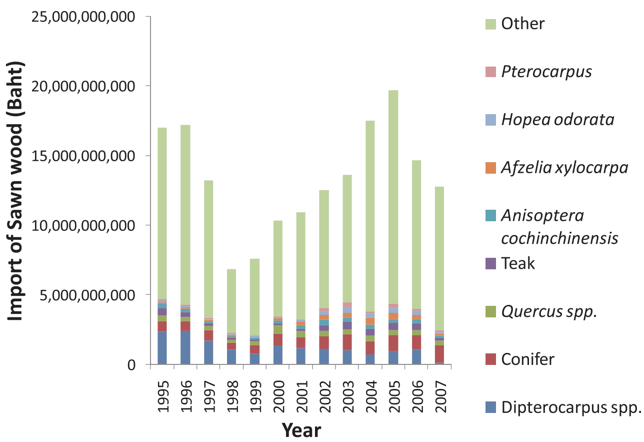

Fig. 11. Transition of imported sawn wood to Thailand by tree species from 1995 to 2007

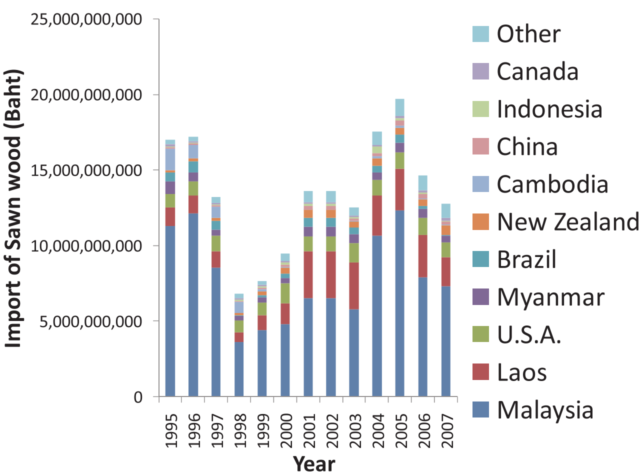

Fig. 12. Transition of imported sawn wood to Thailand by country of origin from 1995 to 2007

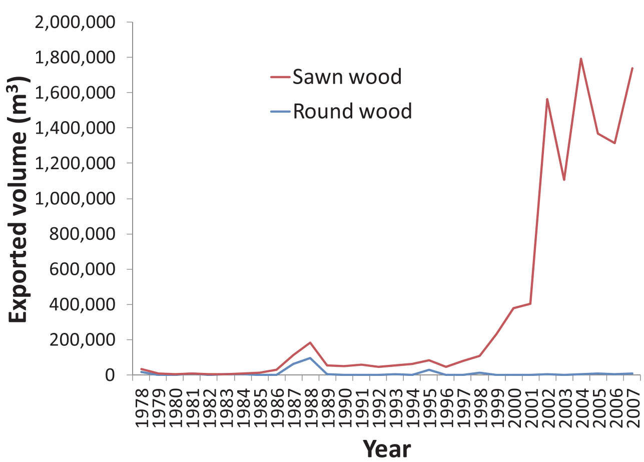

Fig. 13. Transitions of exported round wood and sawn wood from 1978 to 2007

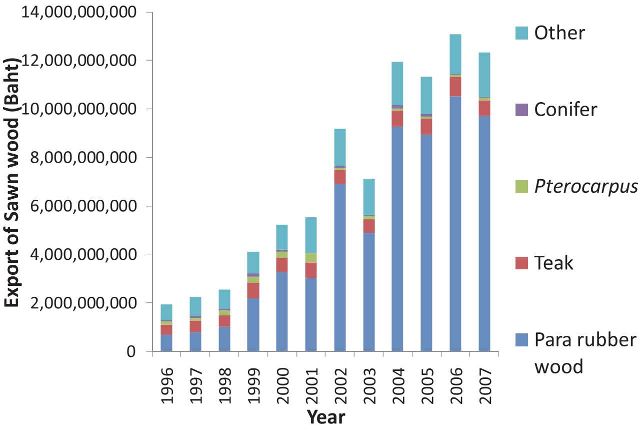

Fig. 14. Transitions of exported sawn wood by tree species from 1996 to 2007

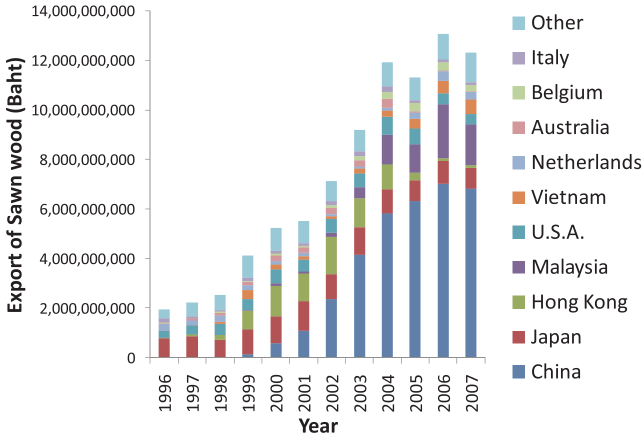

Fig. 15. Transition of exported sawn wood by country from 1996 to 2007

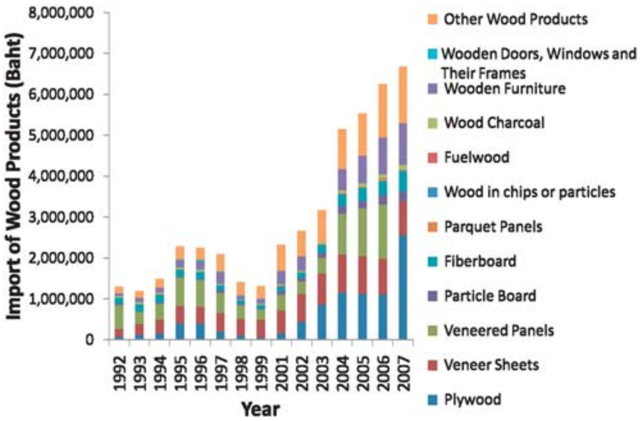

Fig. 16. Transitions of imported wood products to Thailand from 1992 to 2007

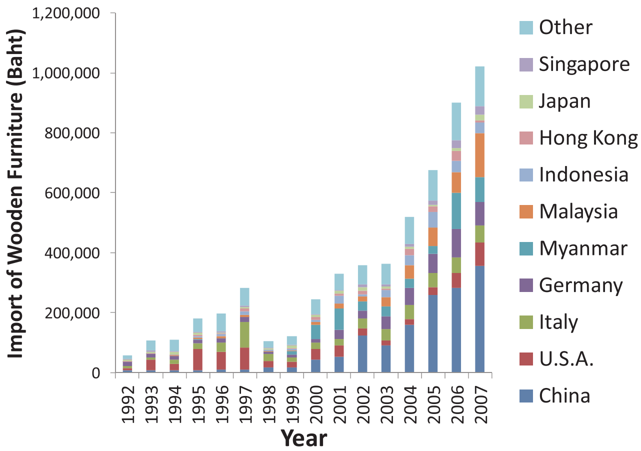

Fig. 17. Transition of imported wooden furniture to Thailand by country of origin from 1993 to 2007

hand, import of round wood from other neighboring countries such as Cambodia and Laos was not constant, although such import showed a high percentage in some years. There was also import of round wood from Papua New Guinea, USA, and the Solomon Islands.

Import of sawn wood decreased from 1997 to 1998, but it then increased until 2005 and showed a drop in 2006 and 2007 (Fig. 11). There were no specific tree species as in the case of round wood, but the percentages of conifer trees and dipterocarpaceae were large. The percentage of dipterocarpaceae was high in 1995, but diminished thereafter. The dependence on dipterocarpaceae was also decreasing in terms of both round wood and sawn wood. On the other hand, the percentage of conifer trees was increasing little by little. Teak sawn wood were exported to Thailand at the level of 500 million baht in value per year from 2002 to 2006.

Sawn wood was mainly imported from Malaysia, and the percentage of this as a proportion of the total was around 50 to 60%. For Laos, the percentage was 10 to 15% in the 2000s (Fig. 12). The percentage for Myanmar was not high, at only 4%. The percentage for Cambodia was also low in the 2000s, although it was around 5 to 10% until 1998. Import from New Zealand could be observed continuously.

Export of round wood was quite limited, but export of sawn wood increased from 2000 (Fig. 13). With this increase in export, import and export of sawn wood were nearly balanced, although import had been much larger than export previously (Table 1). In particular, the export of para rubber sawn wood greatly increased (Fig. 14). Export of teak sawn wood was constant in currency baht.

Export of sawn wood to China grew in the observed period and reached a level around half of the total (Fig. 15). The percentage of exports to Japan was around 40% in 1996 and 1997, but decreased thereafter, although the total amount was rather stable in currency baht. Export to Malaysia was observed steadily in this period. Export to the

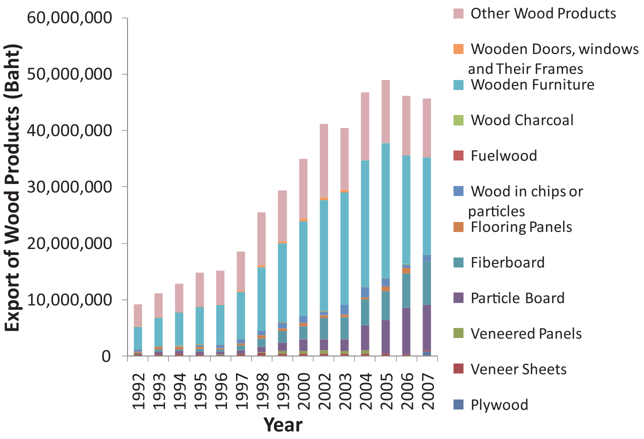

Fig. 18. Transition of exported wood products by country from 1992 to 2007

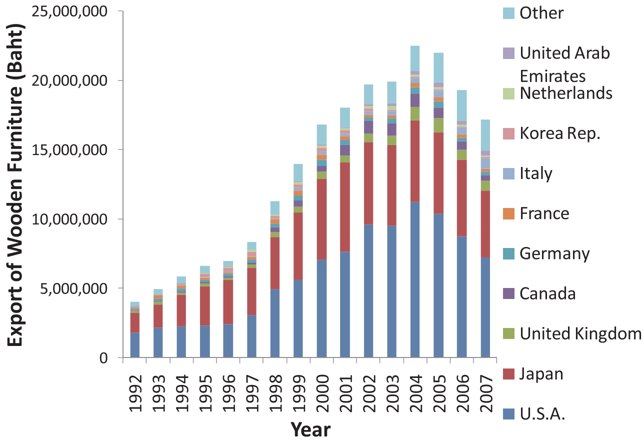

Fig. 19. Transition of exported furniture by country from 1992 to 2007

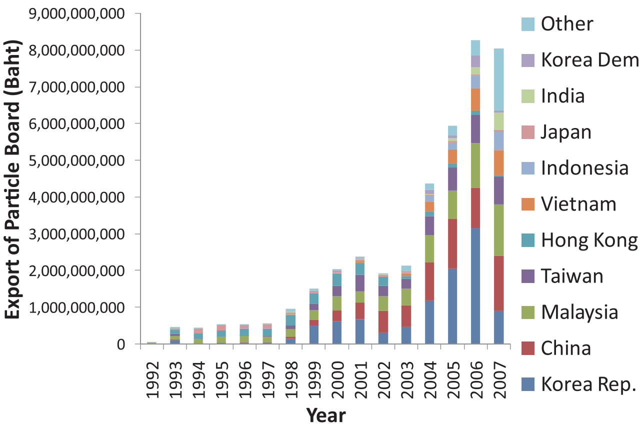

Fig. 20. Transition of exported particle board by country from 1992 to 2007

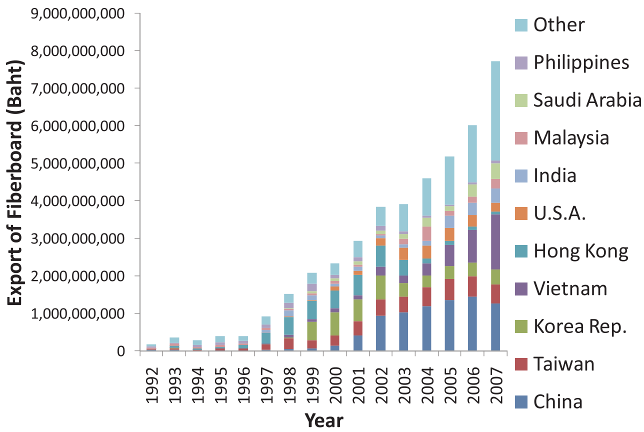

Fig. 21. Transition of exported fiberboard by country from 1992 to 2007

USA was high in the 1990s and somewhat high to Vietnam around 2000.

4) Transitions of import and export of wood products

Import of wood products such as plywood, veneer sheets, and veneered panels increased (Fig. 16). In particular, the growth of plywood was large. The percentage of wood furniture and other wood products also increased in the 2000s. The import of veneer sheets steadily increased (there are no statistics on veneered panels in the forestry statistics for 2007). The increase in the import of furniture was large, especially in recent years. The main exporter of wooden furniture was China after 1998 (Fig. 17). There were constant levels of import of wooden furniture from Germany and Italy. There was importation from Myanmar after 1999 and import from Malaysia also increased gradually during this period. Import from USA decreased, although it was high in the 1990s.

As a whole, export of wood products to Thailand increased (Fig. 18). Export of furniture was most important among wood products, covering around 40 to 50% of the total amount. Recently, export of fiberboard and particle board has increased. Major exporters of furniture have been USA and Japan (Fig. 19). The total amount of export of wood products to Thailand increased and peaked in 2004, after which the trend has been one of decrease. Export of particle board increased, and it showed rapid growth after 2004. The main exporters of particle board were Malaysia, China, and South Korea. Export of this material to Hong Kong decreased after 2003. Continuous export to Taiwan was observed from 1998 (Fig. 20). Export of fiberboard also increased (Fig. 21). Export of this material to China and Vietnam increased recently, and continuous export to Taiwan was observed. On the other hand, export to Hong Kong, Malaysia, and the Philippines decreased.

5) Transition of paper and paper pulp industries

The transition of domestic production of paper is shown in Fig. 22. Production of craft paper and printing & writing paper has decreased drastically since the 1990s. The

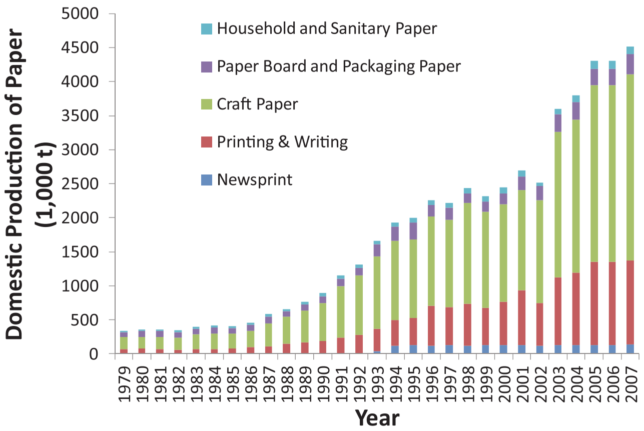

Fig. 22. Domestic production of paper from 1979 to 2007

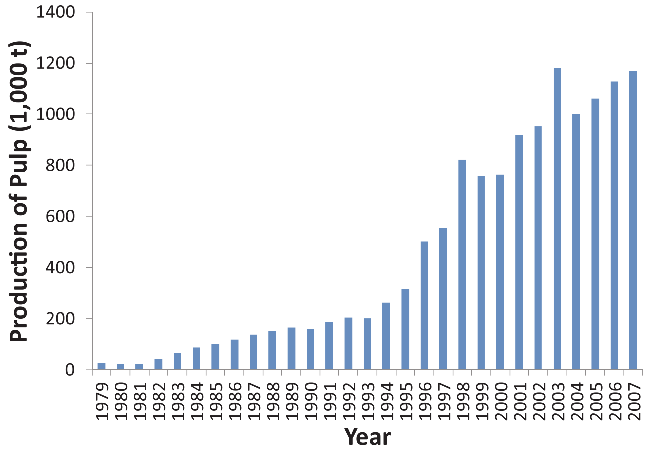

Fig. 23. Domestic production of pulp from 1979 to 2007

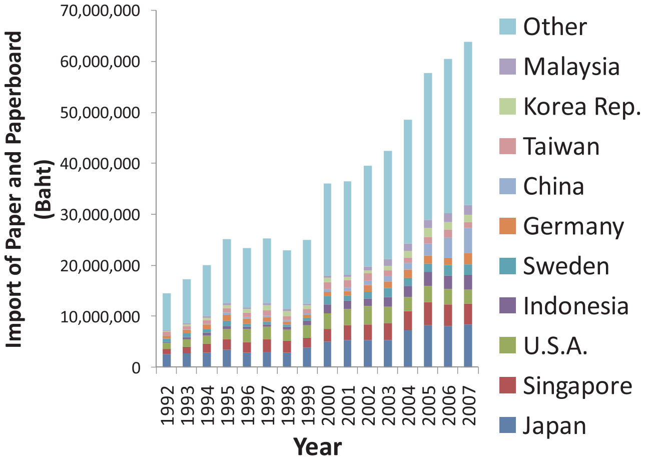

Fig. 24. Transition of imported paper and paperboard to Thailand by country of origin from 1992 to 2007

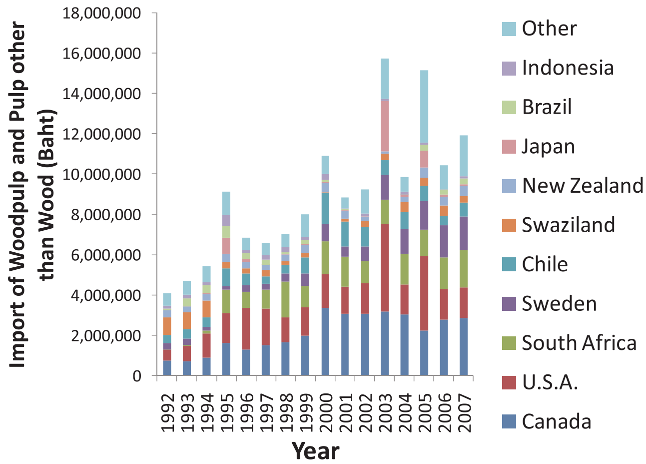

Fig. 25. Transition of imported wood pulp and pulp other than wood to Thailand by country of origin from 1992 to 2007

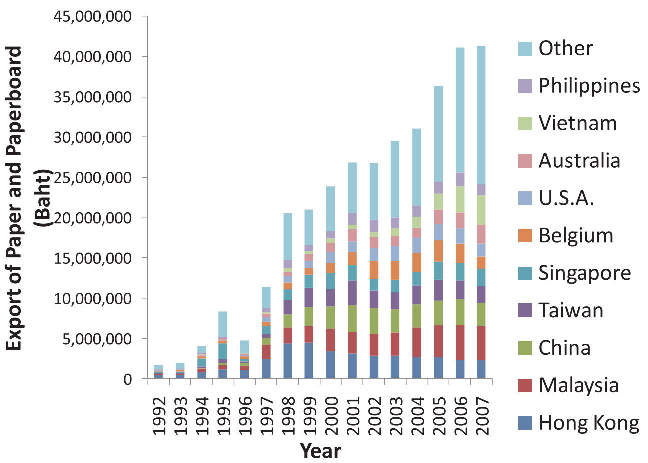

Fig. 26. Transition of exported paper and paperboard by country from 1992 to 2007

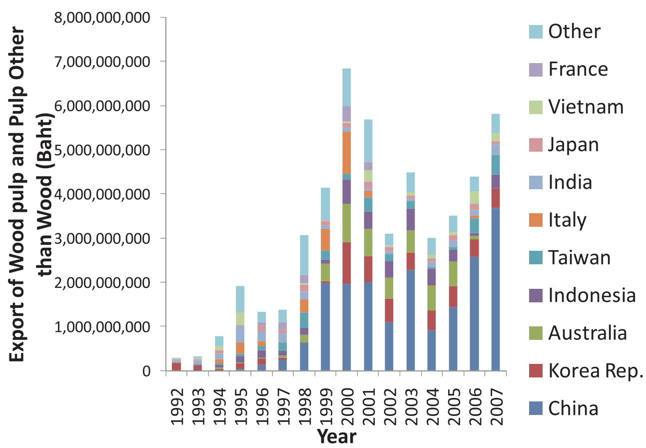

Fig. 27. Transition of exported wood pulp and pulp other than wood by country from 1992 to 2007

production of pulp has increased (Fig. 23).

Import of paper from Japan was high in the whole period (Fig. 24). Paper was also constantly imported from Singapore. The percentage of imports from China has also recently increased. The percentage for the USA was constant at around 10 percent. There was import of paper continuously from Germany, Indonesia, South Korea, Sweden, and Taiwan.

Import of wood pulp and pulp other than wood from Canada was high at around 20 to 30% of the total (Fig. 25). Import from USA, South Africa, and Sweden was also constant. There was constant import from New Zealand and Chile.

Export of paper increased (Fig. 26). Paper was exported to Malaysia at the highest level, and then to China, Australia, USA, Singapore, Taiwan, Japan, the Philippines, and others. The level of concentration on specific countries or fluctuation of export partners was rather small compared with that for other wood products.

In total, 30 to 60 percent of exported wood pulp and pulp other than wood went to China since 1999 (Fig. 27). The export destinations of wood pulp and pulp other than wood changed occasionally. Other main export destinations were India, Australia, South Korea, and Indonesia.

6) Summary of transition of wood processing industries in Thailand

As a summary of the above-mentioned trends of wood processing industries, the following factors have been clarified:

1. Decreased production of wood products after the Asian economic crisis was recovered from and strong growth was shown in some items.
2. Production of sawn wood of rubber increased and much was exported to China.
3. Import and export of sawn wood were balanced according to the growth of export of sawn wood of rubber.
4. Export of fiberboard and particle board to East Asia increased.
5. Export of furniture mainly to USA and Japan were steady.
6. Traditional wood products of teak were the key for much of the import of round wood from Myanmar and sawn wood from Laos.
7. Production of paper increased with economic development.
8. There was export of paper and wood pulp, and wood pulp in particular was exported to China.

Discussion

Thailand has achieved rapid economic growth to become one of the leading countries in Southeast Asia (Fogel, 2009). Production and export of primary industry materials such as rice, rubber, cassava, sugarcane, and maize have played important roles in the national economy, although nowadays their relative importance for the whole national economy is shrinking (Alpha Research, 2010). Expansion of agricultural land brought drastic deforestation in 1980s and 1990s. Efforts toward forest conservation and tree planting strongly initiated in the 1990s (Mahannop 2004). As mentioned in the former studies (e.g. Fisher and Hirsh 2008; Southworth et al. (in press)), Thailand was considered to have entered a recovery stage of forest transition. However, strong initiatives for forest rehabilitation could not be observed. The trend of forest transition of Thailand should be continuously observed based on the reliable national data. Studying the transition in Thailand will also provide insight into the future of forests in countries besides Thailand.

The production, import, and export of round wood, sawn wood and wood products from or to Thailand have a big impact in this region, especially in neighboring countries. Increased export of sawn wood and wood products of rubber, achieved by the replanting of rubber, drastically changed the situation to an excess of import over export of wood products. Most rubber plantations were established in the south of Thailand and the new rubber plantations have also been developed in eastern and northeastern Thailand (Jawjit et al. 2010). However, there are some uncertainty and concerns on the application of rubber plantation to the montane area (Fox J et al. 2011). The productivity and impact on the environment and biodiversity of planting rubber in those regions should carefully be assessed. Export of wood pulp and paper has also become more and more important. Most of those materials were provided from eucalyptus plantations (Jawjit et al. 2006). Instead of conventional wood products, the importance of forest resources, such as rubber and eucalyptus, became larger and larger in the wood processing industry. China became the important trading partner in some items of wood products such as export of sawn wood. On the other hand, there were continuous demands on teak wood materials for traditional wood processing industry. However, the supply of teak wood materials depended markedly on the neighboring countries after a decrease in domestic teak resources and the subsequent logging ban. Given that teak wood resources from neighboring countries are decreasing, expansion and supply of domestic teak wood from tree plantations are highly expected. More efforts for securing of supplies of wood materials should be put on for sustainable development of wood processing industry in Thailand.

In this study, the transition of forestry and wood processing industry was observed using historical forestry statistics. The trade of wood products among countries could be observed using the statistics. However, domestic trade and transportation of wood and wood products between regions or provinces could not be studied in the current situation. Current data collection and summary of production and supply of and demand for wood and wood products were not sufficient. There were differences in the distribution of the forest resources, wood processing industry and consumption among the regions in Thailand. Therefore, the trade between regions or provinces should be monitored. Efforts should also be put into improving the contents and accuracy of statistics instead of the current trend of simplification. Those statistics will be the basic information for further analysis and planning for the future.

Acknowledgements

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The present circumstances of teak wood processing, marketing and future prospects in Northeast Thailand

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Abstract

The present circumstances of teak wood processing, marketing and future prospects in northeast Thailand were studied in order to improve teak plantation management by local farmers. The first is to rationalize the log purchase prices of middlemen or sawmill factories; the second is to simplify complicated formalities on teak trading. To tackle these obstacles, governmental support should be provided to empower the financial and human resources of private forest owners on a cooperative basis. Log auction markets, moreover, can undertake a significant role as follows: A log auction market can provide a farmer with price information, which would otherwise be hard to obtain, in order to eliminate unfair low prices offered by brokers etc., and ensure that materials of the quality and quantity demanded by wood processing contractors can definitely be supplied. The stable just-in-time supply to meet this demand can be implemented, provided a log auction market is established and all base and price / stock information of the market is shared mutually via an information network. Establishment of such log auction markets should be more feasible, if government support can be introduced in the form of loans for purchasing logs and to cover other running costs for log auction markets, etc. For the time being, private forest owner cooperatives or united organizations should undertake the role of management of log auction markets, because such cooperatives have been publicly organized. If a private forest owner cooperative manages a log auction market, members or farmers can expect stable demand for teak logs at a fair auction price, which paves the way for farmers to become motivated to manage teak plantations.

Keywords: teak, farmers, wood processing, log auction markets, cooperatives

Introduction

Natural teak forests are only located in northern and western Thailand. These regions have long gained a reputation as high quality teak furniture production areas. However, the natural teak forests there have declined due to the abundance of teak product exports to developed countries and the supply to the domestic urban markets, hence teak logs harvested from man-made teak forests have replaced the natural source. Conversely, there is poor demand for man-made teak logs in northeast Thailand because this region has no natural teak forests and had no teak wood processing industries until the mid-1990s.

While some teak log markets have already been established and many private teak wood processing facilities operate actively in north and west Thailand, there are also a few teak sawmills and markets in northeast Thailand.

Since 2006, we at the Japan International Research Center for Agricultural Sciences (JIRCAS) have been engaged in cooperative research in close cooperation with the Royal Forest Department (RFD), in developing techniques for nurturing beneficial indigenous tree species, and have also engaged in joint research into a complex business model for farming and forestry, which involves the agricultural management of indigenous tree species, with a focus on teak, in order to support efforts to improve the lives of small-scale farmers in northeast Thailand. This project further develops the Reforestation and Extension project of the Japan International Cooperation Agency (JICA) in northeast Thailand (phase II) (REX II project), which was implemented between 1999 and 2004 (Suzuki 2004), and represented an ambitious attempt to remedy the current economic condition of the small-scale farmer.

The purposes of this paper are 1) to analyze the present circumstances of teak wood processing and marketing; and

2) to show future prospects in northeast Thailand as compared to traditional teak product areas in northern and central Thailand.

Materials and methods

The actual condition of methods of purchasing teak logs, marketing of teak products and management of wood processing facilities were surveyed at teak processing facilities in Udon Thani, Nong Khai, Nong Bua Lam Phu and Loei Provinces in northeast Thailand since 2006. Two private forest plantation cooperatives in central and north Thailand were introduced for comparison with cooperatives in northeast Thailand.

Price information on teak logs and teak forest practices were surveyed at RFD regional offices in northeast Thailand.

Results and discussion

1. Teak processing facility in northeast Thailand

1) Nong Han Furniture (Udon Thani Province)

This facility was established in 2002, and represents a model teak processing facility in the Nong Han area, owned by a policeman. The reason why he started a teak afforestation and processing facility are: he sometimes arrested farmers who cut teak logs for their own consumption without official permission and recognized that teak tree plantations were essential for farmers wanting to get teak logs for their own use. In addition, a teak processing facility was necessary for teak farmers wishing to sell teak logs.

The owner took furniture making training course at the REX center in Yasothon before starting his own business. At present, six craftsmen produce tables, chairs, beds, door panels, robes and floors (Fig.1). The maximum production capacity is 20 sets, which consist of 1 table and 3 chairs, per month. This facility purchases teak logs of 90-120 m^3 from 3 or 4 neighboring farmers each year. The average price for teak logs of 6 m in length and 50 cm girth is 200 baht (JPY 800) each.

The main market for teak furniture is the Udon Thani area, and the product quality is so good that they are acclaimed by customers. Furthermore, the furniture is also exported to USA through an American middleman living in Udon Thani city.

The current problems of his business are: firstly the limited number of teak product markets around the Udon Thani area, and secondly, teak farmers lack sufficient incentive to own teak forests because teak product markets are so narrow and the distribution quantity of teak products so restricted, and thirdly, the lack of money to buy logs and expand his facility. Recently, the owner is anxious over the problem of farmers cutting teak trees and replanting them with eucalyptus or rubber trees.

Fig.1. Teak furniture processing works at Nong Han Furniture, Udon Thani Province

2) Nong Bua Lam Phu Forest Plantation Cooperative (Nong Bua Lam Phu Province)

This plantation cooperative was established in 2000 by the Forest Plantation Act. A furniture facility was built in 2002. The territory of this cooperative encompasses 6 counties in Nong Bua Lam Phu Province and 311 members. There are 13 board members, with 2 persons elected per county.

This cooperative provides some teak log price information, secures middlemen for members and manages wood processing and sales businesses. These activities are effective trials to overcome marketing problems facing such small-scale farmers.

The management conditions of this cooperative and willingness of members were surveyed. Of all the members, 80% of the members who lived in the territory planted teak trees were under the 3,000 baht project (silviculture subsidy project) and 20% of members were non-resident forest owners. The teak forest area owned by members was 8,000-9,000 rai (1,300-1,500 ha). At the beginning of the project, the members hoped that they could harvest and gain 400-500 baht per tree, 6-7 years after planting the teak seedlings. However, as they found that it was impossible to gain the expected income within such a short period, they rapidly lost their enthusiasm for teak plantations. The cooperative constructed a wood processing facility financed by an NGO's low interest loan in order to show the potential of processing value-added teak products from woods with smaller trees.

As of 2009, the teak processing facility produced windows (100-150 per month), doors (20 per month), swing chairs and etc. (Fig. 2). This facility includes a dry kiln and an underwater log stock site. The total number of employees was 6, of whom 4 worked at the sawmill and 2 at the furniture facility.

The cooperative obtains teak logs easily because many farmers want to sell them and can process a maximum of 150 m^3 teak logs per year. This volume indicates that it is impossible to buy all the wood harvested by members, in other words, oversupply. The market for the teak products is also limited around the facility due to the small-scale nature of production. Fortunately, a big company namely "Green

Fig.2. Teak furniture at private plantation cooperative, Nong Bua Lam Phu Province

Fig.3. Finger jointed teak lumber at Nong Khai ANP Import and Export Co.Ltd., Nong Khai Province

Group" contacted this cooperative through the RFD website last year and has already sold 100 sets of door frames for 200, 000 baht.

The price of teak logs is decided by the cooperative committee based on information from middlemen and the Forest Industry Organization (FIO) (Noda et al. 2011). A committee member said that though the quality of teak products (oven-dried) made by this facility was relatively good compared to natural dried products coming from north Thailand, the price was cheaper due to competition with the latter.

Current problems facing this cooperative include the lack of funds to buy logs, lack of skilled workers and decline in motivation of members to maintain teak forests caused by low log prices.

3) Nong Khai ANP Import and Export Co. Ltd. (Nong Khai Province)

This company was established in 2003 and is the largest teak sawmill in Nong Khai area. The main products are boards and finger joint lumber, the teak production volumes of which amount to 14 and 34 m^3 per month respectively. The channels for purchasing teak logs include farmers' offers and negotiation with farmers based on information from middlemen. Though the areas in which teak logs are purchased are Udon Thani and Nong Khai Provinces, this company also collects teak logs from north Thailand and imports them from Laos casually because teak logs have tended to be in short supply recently in Nong Khai Province.

The reasons why farmers around this area offer to sell teak logs are the relatively high prices and cash settlement. Furthermore, this company has a price table of logs and the prices have remained unchanged since the company was first established.

This company has 20 regular employees and 60 part-timers. The pay is 10,000 baht per month and 150 baht per day, respectively.

The teak products are mainly sold to the markets in Bangkok (60%), Nong Khai area (10%) and the Udon Thani area (30%). The transportation fee to the Bangkok market, which is the most important to this company, is 8,000 baht per lorry-load, 500 ft^3 (=14 m^3).

A distinct feature of this company is the introduction of a finger joint machine in order to process the glued lumber from small teak pieces (Fig. 3). When considering the short history of teak plantations and the majority of small diameter log production, the introduction of the finger joint machine will be key to making value added teak products in this area.

4) Predakamai (Loei Province)

This sawmill was established in 2002, followed by a furniture and wood crafts shop in 2006. Teak products include doors (10-20 pieces/day), window frames (200 pieces/day), door frames (50-100 pieces/day), transoms (100 pieces/day) and souvenirs, in addition, teak sawdust for mushroom beds and teak wood powder for aromatics. These products are sold in Udon Thani and Kong Ken areas of northeast Thailand.

This sawmill has 5 regular employees and 30-40 part-timers. The pay is 10,000 baht per month and 150 baht per day, respectively. Seven to eight pieceworkers make windows (15 baht/piece) and table sets (2,000 baht/set). As these kinds of teak products are popular in northeast Thailand, this shop cannot take up orders from customers.

The owner buys teak logs from small-scale farmers who own 10-20 rai of teak forest. As the farmers wish to change their teak forests to rubber tree forests, there are many offers from farmers wishing to sell teak logs. This situation results in the low price of teak logs, rendering it a buyers' market. The price table is made by staff taking log girth, uses and operation costs into account and does not reflect the FIO price because FIO decides on the teak log price based on the relatively higher tree age (over 20 years old) and better quality logs than the teak logs produced in this area. In general, the price of FIO teak logs is twice that of those in this area.

In addition, this sawmill purchases 20,000-30,000 ft^3 (540-810 m^3) of teak lumber per month, 70% of which is imported from Laos via a middleman and 30% of which comes from the Loei area. The prices of teak lumber from Laos are 280 baht/ft^3 with 4 by 4 inches and 350 baht/ft^3 with 5 by 5 and 6 by 6 inches.

Table 1. Prices of teak logs by girth

	Address (Province) Teak consumption	A	B.	C
		Udon Thani	Udon Thani	Loei
		24-25 m^3/yr	800-950 m^3/yr	8,000-12,000 m^3/yr
1	Price per tree (at facility)	Length 4m, GBH more 50 cm; 200 baht/log	Length 4 m, GBH 50 cm; 300-500 baht/log GBH 50-90 cm; 600-800 baht/log GBH 90-100 cm; 1,000 baht/log	
2	Price per tree (at plantation)	GBH 76 cm; 400 baht/tree		Avg. 150 baht/tree GBH under 40 cm; 60 baht/tree GBH 40-50 cm; 100 baht/tree GBH 50-60 cm; 170 baht/tree GBH more 60 cm; 200 baht/tree
3	Price per rai (at plantation)	13 yrs old, 2 × 2 m; 16,000 baht/rai		

Source: Interview survey with owners

The owner of this sawmill expects to gain sufficient volume of teak logs in the next decade and plans to introduce finger joint machines.

For example, the prices of teak logs from 3 companies in northeast Thailand are shown in Table 1.

2. Current situation of private forest plantation cooperatives in central and north Thailand

1) Lop Buri Forest Plantation Cooperative (Lop Buri Province)

This cooperative was established in 2000 and is located in central Thailand, north of Ayutthaya. There are 206 members, 7 of whom are board members. If a farmer wants to join the cooperative, he or she must have been living in Lop buri Province and must own man-made forests. In addition, a registration fee (100 baht) and 50 units or more of subscription (10 baht/unit) are essential. Cooperative members were familiar with information on forestry-related laws and regulations. Furthermore, the cooperative precedes the purchase of teak logs from members who wish to sell logs to the cooperative.

Harvesting work is left to time-workers employed by the cooperative. Teak logs exceeding 40 cm girth are sold to 2 furniture facilities in this area and the remaining logs are sold to any willing customers (Fig. 4). The prices of teak logs are 700-1,000 baht per log with 50-80 cm girth and 2,500 baht per log with 80-100 cm girth, which are twice as high as elsewhere in the Udon Thani area and close to FIO prices. According to our sawmill survey carried out in north Thailand, all the owners said that it was impossible to buy logs with high FIO price. Considering this, the reason why the sawmills in this Lop Buri area can charge high prices for teak logs are its good location close to the major consumption center of Bangkok.

The cooperative sells teak logs to customers at prime cost plus 20% and pays a dividend to members when the cooperative gains a surplus. The surplus was 5% in 2006 and 2007.

We asked the chairman of this cooperative about the establishment of log auction markets, he answered that the market was necessary to gather together many suppliers and consumers. Conversely, he said that the current problem of this cooperative was the lack of a loan system to manage the cooperative. This means that the cooperative will be unable to set up a log auction market without some financial support by the government (Furuya et al. 2011).

Fig.4. Teak log selling on the roadside in front of the cooperative at Lop Buri forest plantation cooperative, Lop Buri Province

2) Don Mol wood products cooperative (Phrae Province)

This cooperative, which is located in the suburbs of Phrae city, was established in 1997. Its members include small-scale wood craft facilities (200 owners), forest owners (50 persons) and teak wood products shops (13 persons). If someone wants to join the cooperative, he or she must pay a registration fee (100 baht) and 100 units or more of subscription (10 baht/unit). The members have a dividend of 5-10% when the cooperative gains a surplus. The main industries of the Don Mol area are forestry and wood processing. There are 9 wood products cooperatives in Phrae Province, 3 or 4 of which are in this area. This cooperative is the largest in Phrae Province and is characterized by the concentration of many wood processing facilities at the same site. The site is divided into 74 blocks and 18 owners have been operating there (Fig. 5).

Fig.5. Concentration of teak processing works at Don Mol wood products cooperative, Phrae Province

The rental fee for each block is 200 baht per month and the owners pay for the cooperative.

The members of the cooperative consume teak logs at a rate of 800 m^3 every month. Half come from FIO forests and the rest from private forests. The owner buys logs by him/herself, but the owner has to pay 100 baht/m^3 to the cooperative as a service charge.

The teak processing facility here can purchase FIO logs at relatively higher prices because they require high quality logs for high-grade furniture. As middlemen give information on the production of teak logs of private forests to the cooperative, it is not difficult for the cooperative to buy teak logs.

A secretary of this cooperative said that 40,000 m^3 of teak logs were produced every year, half of which were supplied from FIO forests. The demand for teak logs is so high that diversion of tree species from teak to another is uncommon in this area. The secretary of the cooperative is aware of the need to establish log auction markets, but considers it impossible because the cooperative lacks money to buy logs from farmers, which means it will be possible to establish log auction markets if the government makes funding systems for log auction markets available. This situation is the same as that faced by the Lop Buri Forest Plantation Cooperative.

3. Comparison of teak log prices between north and northeast Thailand

The teak log prices when purchasing from farmers are almost the same as north and northeast Thailand, but the FIO price in north Thailand exceeds that of northeast Thailand. Labor costs are almost the same between north and northeast Thailand. This means the teak processing facility in northeast Thailand would have to obtain cheaper logs and make high quality products like north Thailand. These conditions are essential to ensure northeast Thailand's wood facilities can compete in national and export markets against those in north Thailand, which have already established a brand image.

Table 2 shows the price information and quality estimation of teak logs between north and northeast Thailand. North Thailand has a long history of teak plantations and wood processing industry. The larger diameter teak logs are popular and the FIO price table is used by customers.

Table 2. Price information and quality estimation of teak logs

	North Thailand	Northeast Thailand
Price information	Based on the products price, FIO price table	Middlemen, RFD price table
Estimation of teak logs by customers	High quality	Area unsuitable for teak plantation

Source: Interview survey with stakeholders

Conclusions

Teak is a good example of a relevant major issue. For teak, there are a number of issues, among the first of which is the optimization of timber purchase prices from middlemen and wood processing facilities, and secondly, the need to simplify the cumbersome procedures required for the market development and sale of teak. To resolve these issues, the personnel and financial strength of forest owner cooperatives is necessary, and government support is also essential. Also, a log auction market can be effective in providing pricing information to teak farmers who find it difficult to obtain such information, eliminating the unreasonably low log prices presented by middlemen, and providing an outlet where wood processing facilities can obtain raw materials of the required quality and volume. By establishing such log auction markets in each region, and sharing the cargo and pricing information of each log auction market via an information network, a just-in-time system of stable supply can be created for teak consumers. Such approaches will likely encourage more farmers to manage teak forests.

Acknowledgements

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Current situation of teak farm forestry after Economic Tree Plantation Promotion Project in Northeast Thailand

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Abstract

Current situation of teak farm forests after the Economic Tree Plantation Promotion Project (1994-2002) were analyzed based on questionnaire surveys on teak farm forest owners in the northeast of Thailand. A low implementation rate of thinning was one of the key problems in management. Many respondents (59%) were satisfied with their tree plantations even in the northeast of Thailand. However, planters were still concerned about the market and the achievement of fair trade in this region. Planters also expected financial support for managing their forests. Not only technical assistance in the initial stage of tree planting but also continuous support in terms of socio-economic aspects was expected. The level of satisfaction with tree planting was directly related to the growth conditions of teak stands. It was suggested that site selection and research on suitable sites for teak tree planting were key tasks for the promotion of tree planting.

Keywords: farm forestry, Economic Tree Plantation Promotion Project, teak (*Tectona grandis*), Northeast Thailand, questionnaire survey

Introduction

The Economic Tree Plantation Promotion Project was conducted from 1994 to 2002 in Thailand (Mahannop 2004). Most plantations were established during the initial period from 1994 to 1997 before the project budget was reduced due to the Asian economic crisis (Mahannop 2004). Subsidies were provided to the participants step by step over the initial 5 years for farm forest management. The Royal Forest Department (RFD) project evaluation report (2002) pointed out that many plantations were abandoned, but large areas of tree plantations were established all over the country through the project. The report also mentioned the importance of marketing and continuous care after the 5 years of assistance by the project. Many studies were conducted targeting factors that affect participation in tree planting around the year 2000 (e.g. Buaban 1999; Tangittam 1999; Rachadawannapong 2000; Saengpan 2003).

Natural teak forests are distributed from the north to the east of Thailand, and these have contributed to the national and local economy (Gajaseni and Jordan 1990). However, as a result of a decrease of teak resources from domestic natural forests and the resultant logging ban in 1989, teak log supply has been highly dependent on the import of logs and sawn wood from neighboring countries, such as Myanmar and Laos. Teak was first planted in 1906, and there is a long history of teak planting by the public sector (Kijkar 2001). Teak is one of the most popular tree species for planting in Thailand. However, the decrease of resources in surrounding countries is considered to lead to high demand for domestic teak wood from the plantations. Therefore, the establishment of a system for providing teak logs from plantations in a sustainable way is urgently required.

Northeast Thailand has a large human population (Alpha Research 2010). The economy depends more on agricultural production than in other regions. The main crops are rice, sugarcane, cassava, and maize. Northeast Thailand previously had large areas of forest (42.0% in 1961) on comparatively gentle terrain, but the forest area dropped through land conversion to agricultural land, and the forest area as a proportion of the total became the lowest among the regions of Thailand (12.5% in 1998) (RFD, 2008). Fluctuations in cash crop price and irregular weather cause instability of farmers' income in this region (Kasem and Thapa 2011). One option for farmers is to adopt teak

Table 1. Total planted areas (rai) of five popular tree species established by the Economic Tree Plantation Promotion Project during 1994-2001

Species	Central	North	Northeast	South	Total	%
Tectona grandis	103,014	492,784	377,307	5,284	978,389	45%
Azadirachta indica	43,066	37,598	401,719	1,905	484,288	22%
Pterocarpus macrocarpus	13,038	6,233	448,680	161	468,112	21%
Azadirachta excelsa	5,908	123	4,232	42,967	53,231	2%
Afzelia xylocarpa	523	165	41,682	40	42,410	2%
Sub-total of 5 main species	165,549	536,903	1,273,620	50,357	2,026,430	92%
Total	219,851	545,763	1,352,495	75,578	2,193,687	100%
Percentage by region	10%	25%	62%	3%	100%	

forest management on part of their land in order to stabilize the total long-term profitability of their land. Growth of teak forest in the northeast of the country is not always as good as that in the north, but there are suitable sites for teak planting where teak farm management can bring sufficient profits (Sukchan and Noda this issue). However, there is high competition among types of land use, such as cash crops, rubber, and eucalyptus plantation. Therefore, it is important to improve the socio-economic conditions surrounding teak forest management for developing and maintaining teak farm forests in this region.

Time has passed since the project's end, and new problems may have arisen. Therefore, the objective of our study is to determine the current situation of teak farm forest planters and their management, focusing on the northeast of Thailand where there is high competition among types of land use.

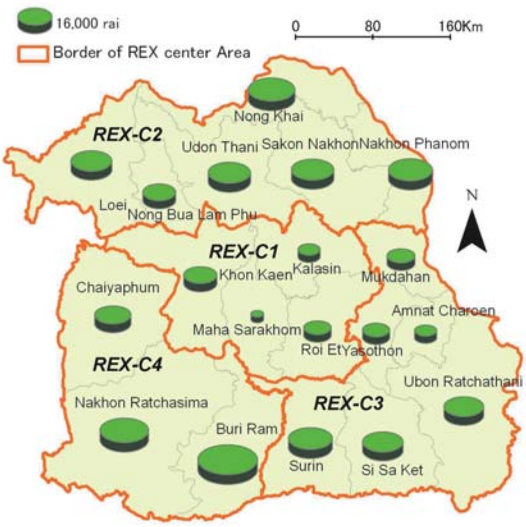

Fig. 1. Planted areas of teak in each province through the Economic Tree Plantation Promotion Project from 1997 to 2001

Materials and method

Firstly, regional characteristics of tree plantation were determined using a registration database of participants in the project from 1994 to 2001 constructed by RFD. The Reforestation and Extension Project in the Northeast of Thailand (REX) supported by Japan International Cooperative Agency (JICA) established four centers in different provinces of the region: REX-C1 in Maha Sarakam, REX-C2 in Udon Thani, REX-C3 in Yasothon, and REX-C4 in Nakhon Ratchasima. These centers played an important role for implementing the activities for promoting tree planting such as seedling production, forestry extension, training, demonstration plantation, and nursery technique development. Therefore, items were summarized at the level of province or REX center using information on the address of residence of planters and the location of plantation sites. The results were mapped using the software ArcGIS 9.3 (ESRI Inc.). Statistical analysis was performed with SPSS 15J software package (SPSS Inc.). Secondly, the results of a questionnaire survey conducted from 2005 to 2006 by the Department of Economics in the Research Bureau of the RFD were analyzed to understand the current status of planters, teak farm forest management, and the opinions of planters on tree plantation. A total of 148 answers of teak planters in the northeast of Thailand were analyzed. Statistical analysis on questionnaire survey was performed with JMP 8 (SAS Institute Inc.). Lastly, the results of teak farm forest establishment through the project were discussed.

Results and discussion

1. Regional characteristics of establishment of plantations in the northeast of Thailand

Teak was one of the most planted tree species, occupying about 45% of the overall planted area. About half of teak plantations were established in the north of Thailand, but 39% of these were established in the northeast of Thailand (Table 1). It is observed that more tree plantations were established in the provinces associated with REX-C4 and REX-C2 than with REX-C3 and REX-C 1 (Tukey's HSD, $p < 0.05$) (Fig. 1). In addition, the average area of teak plantation was larger in the provinces associated with REX-C4 than with the other centers

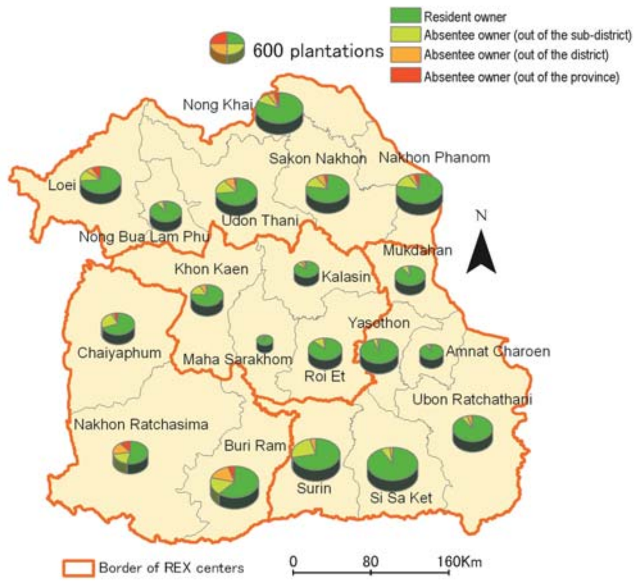

Fig. 2. Proportions of resident owners (group R) and absentee owners (out of their own sub-district (Tambon) (group T), out of their own district (Amphoe) (group A), and out of their own province (Changwat) (group P)) in each province through the Economic Tree Plantation Promotion Project from 1997 to 2001

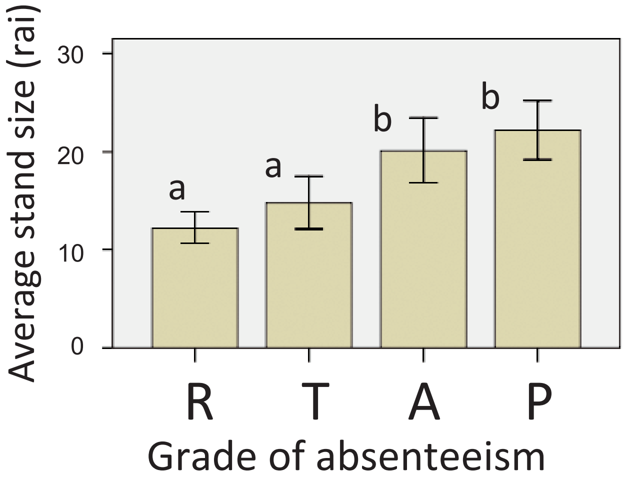

Fig. 3. Differences of average sizes of teak stands according to the grade of absenteeism of teak forest owners. The error bars show the 95% confidence interval. The explanation on the grade of absenteeism was given in the caption of Fig. 2.

(Tukey's HSD, $p < 0.05$). A previous study revealed that the grade of absenteeism of planters is one of the factors that affect the non-reforestation attitude after harvesting in Japan (Noda and Hayashi 2004). Thus, the grade of absenteeism of planters was calculated and summarized for each province. The percentage of absentee owners, who planted out of their own district and out of their own province, was high in provinces around big cities in the region, although most planters were resident owners in rural areas (Fig. 2). The average tree plantation area became larger according to the grade of absenteeism, such as for resident owners (group R) and absentee owners (out of their own sub-district (group T), out of their own district (group A), and out of their own province (group P)). The average sizes of teak stands of absentee owners P and A were larger than those of planters T and R (Tukey's HSD, $p < 0.05$) (Fig. 3).

2. General status of teak planters

General status of teak planters of farmers, non-farmers and all respondents were summarized in Table 2. The average age of respondents was 57 years old. Their main occupation was agriculture (66%). Half of the respondents were full-time farmers. Some ten percent of respondents were in private business and were officers. Most respondents had graduated from primary school and about 30% of respondents had graduated from college. This means that many highly educated people also joined the project. The average land holding size was 77 rai. On average, nearly half of that land (36 rai) was utilized for teak plantation. The average land use was 14 rai for cash crops, 12 rai for paddy fields, 4 rai for fruit gardens, and 10 rai for other land uses (n=94). The average monthly income and expenses were 20,618 baht and 13,948 baht, respectively. The average amount of debt was large, at around 430,000 baht. The average number of laborers in the family was 2.85 persons. Two types of planters, i.e. farmers and non-farmers, are included in the above-mentioned figures. Non-farmers generally include those with higher education (Chi square test, $p < 0.05$), larger land holding, larger teak plantation, larger monthly income and expenses, larger debts, and smaller number of laborers in the family compared with farmers (Tukey's HSD, $p < 0.05$).

3. Management of teak farm forests

Sixty percent of respondents planted trees using family labor and 36% hired laborers from outside. Most plantations (80%) had been established on a flat area, reflecting the rather gentle terrain of the northeast of Thailand. Only 11.6% of plantations had been established on a slight slope to a mountainous area. Soil type was most commonly loamy sand (77%), followed by loamy clay (19%) and laterite (7%). Very narrow spacing, such as 2x4 m (40%), 2 x2 m (19%), or 2x3 m (15%), was adopted because more than 1,250 trees had to be planted to participate in the Economic Tree Plantation Project as a requirement of the initial phase. The proportion with a survival rate "higher than 70%" was 62%, "50 to 70%" was 25%, and "less than 50%" was 13%. 57% of respondents used some kind of

Table 2. General status of teak planters among farmers, non-farmers, and all respondents

Item	Farmers (n=98)	Non-farmers (n=50)	All respondents (n=148)
Age	58.3	55.0	57.1
Average family labor (person)	3.02	2.46	2.85
Land use			
Average land holding (rai)	64.0	105.9	77.4
Average paddy area (rai)	13.9	8.9	12.3
Average crop field area (rai)	17.5	7.7	14.4
Average orchard area (rai)	2.7	5.7	3.7
Average teak plantation area (rai)	21.1	68.8	36.4
Average other land holding (rai)	8.7	14.8	10.6
Average monthly income (Baht)	9882	41094	20620
Average monthly expense (Baht)	8612	23950	13947
Average debts (Baht)	266146	824424	430638
Education level			
Primary school	75	7	82
Secondary school	15	4	19
Vocational certificate	3	5	8
Bachelor's degree	3	27	30
Others	1	5	6

fertilizer on their teak plantations. Pruning was practiced in 87% of teak stands of respondents. Only 22% of respondents took preventive measures against damage by blight and insects. Thirty percent of respondents conducted thinning. The main objective of thinning was to accelerate the growth of the remaining trees (70%), following by selling wood (28%) and reducing tree density (23%). 54% of respondents recognized that their present tree stands were too dense (54%) or moderately dense (41%). The methodology of thinning was mostly low thinning (60%), simply related to the objective of thinning. 26% of respondents conducted high thinning and 16% of respondents conducted systematic thinning. Most of the thinned wood (67%) was used for household use because low thinning was mainly conducted. 22% of thinned wood was sold and 14% was utilized for private wood processing business. Only 5% of thinned trees were unutilized.

Narrow spacing was selected because of the requirements for being approved as a tree plantation by the project in order to receive subsidies (more than 1,250 seedlings/ha had to be planted at the initial stage (625 seedlings/ha after a revision in 1999)). Therefore, it was necessary to conduct thinning, but the implementation rate was low, at only 30%. More than half of respondents felt that their teak plantations were too dense. Many respondents conducted low thinning to help the remaining trees to grow and used the thinned wood in their house. However, some conducted high thinning to sell wood that had reached a merchantable size. More people would conduct low thinning if they could sell small thinned wood. However, at present, postponement of thinning was delaying the growth in diameter of trees and also delaying the time until the trees reach a merchantable size. Daring to make the decision to conduct thinning will be necessary to avoid this vicious circle.

4. Planter's opinions on teak farm forest management

Planters evaluated the growth of their teak stands as good (21%), moderate (62%), or bad (17%). Many respondents (59%) were satisfied with their tree plantations, followed by moderately satisfied (29%) and unsatisfied (12%). The main purpose of tree planting was to obtain a subsidy from the government (74%) and the second was to sell trees (67%). Many respondents also gave reasons of improving the environment (59%) and using the wood for household use (56%). 32% of respondents planted trees for their own wood processing business, that is, they were to use the planted trees as raw material. Planters experienced the following difficulties: lack of money (73%), soil with low fertility (43%), occurrence of damage by blight and insects (31%), occurrence of wild fire (30%), slow growth (28%), and regulations of the RFD (22%). Types of support expected from the government were for marketing and fair trade (71%), followed by financial support (64%) and soft loans (50%), and then technical and knowledge enhancement such as consultation with the people in charge (44%), training in wood processing (33%), technical knowledge (32%), water supply (31%), and training and materials for silvicultural techniques (30%). Half of the respondents had hopes to carry out additional planting, but the other half did not because of a shortage or lack of land that could be additionally allocated to tree planting.

Respondents felt difficulties not in terms of technical or silvicultural aspects but rather from a lack of funds. They expected support from the government in terms of socio-

Table 3. Cross-tabulation table between the degree of satisfaction with tree planting and certain variables

Variable	χ^2 value	Probability	Category	Satisfaction with tree planting		
				Satisfied	Med./Unsatisfied	All respondents
Growth conditions of trees	19.606	<0.001**	Good	28	2	30
			Medium	40	43	83
			Bad	10	11	21
Slow and stunted growth is a problem	4.273	0.0387**	Yes	15	18	33
			No	55	28	83
Do you want to plant more trees?	13.128	0.0003**	Yes	49	17	66
			No	28	37	65
Farmer/Non-farmer	0.156	0.6931	Farmer	52	38	90
			Non-farmer	30	19	49
Land-holding class	1.647	0.4388	>80rai	13	14	27
			30-80rai	26	15	41
			<=30rai	14	9	23
Age class	0.011	0.9173	>56 years old	40	27	67
			<=56 years old	40	28	68
Income class	0.429	0.5126	>10000B	24	21	45
			<=10000B	44	30	74

economic aspects such as marketing, fair trade, financial assistance, and soft loans. Technical assistance may be necessary for implementing thinning, but assistance in terms of socio-economic aspects was strongly needed under the current situation when teak stands have already been established. Many planters complained about the regulations or procedures for harvesting and transporting teak while in the field, but not many respondents specifically mentioned difficulties with the regulations in our questionnaire survey. At any rate, RFD should positively strengthen assistance from the above-mentioned viewpoints. Private Forest Plantation Cooperative can also play an important role. Therefore, the strengthening of the role of PFPC is also a very important issue for the RFD.

5. Factors related to the degree of satisfaction with tree planting

The degree of satisfaction with tree planting can be a good indicator of the evaluations of teak planting by the respondents. Therefore, factors related to the degree of satisfaction with tree planting were investigated using Chi square test. The status of respondents, such as land-holding type, age, education level, farmer/non-farmer, and income, was not found to be related to the degree of satisfaction. In fact, the level of satisfaction was simply related to the growth of teak stands (Table 3). Satisfied planters were more likely to pursue additional planting. This also shows that the degree of satisfaction is a good indicator of the true feelings of respondents.

Many respondents evaluated the growth of their teak stands as moderate and were satisfied with tree planting. Half of the respondents still hoped to plant additional trees. Therefore, the overall evaluation of teak planting by the respondents who had maintained their tree plantations was not bad. The degree of satisfaction with tree planting was directly related to the growth performance of teak stands. Teak farm forest owners were satisfied when their teak stands showed good growth and vice versa. Plantation sites were not carefully selected in the initial phase of the promotion project. Research on suitable sites for teak plantation should be conducted, and information should also be provided to people in an easily understandable way.

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Financial analysis of private teak plantation investment in Thailand

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Abstract

This study was to explore investment return of private teak plantations by financial analysis of data gathered from teak owners. The financial analysis was carried out to estimate NPV at 10% discount rate and IRR by 4 factors of log prices, yields, costs and rotation periods. This study designed teak plantation models with 2x4 meters spacing and cutting rotation at age 15, 22 and 30 years for analysis. We set low and high levels for the yield and cost factors, and used FIO and broker prices for the price factor in order to investigate profitability. In the field survey, the teak logs were mostly sold to brokers at lower price ranging from 1,900 – 11,000 Baht/m^3. The broker prices were quite lower than FIO prices in terms of logs over 15- year-old. The results of financial analysis showed all positive NPV value and profitable, and yield and price were critical factors affecting profit of teak plantation investment. The brokers bought teak logs by volume or tree system, the price by tree got lower profits than by volume. Therefore, the private plantation owner must concern how to get high yield and price. The teak plantation should be selected on suitable site to reduce risk of investment. It was recommended that the appropriate rotation should be 20-25 years. However, the MAI was also another factor to be taken in consideration on rotation. If it was continuously increasing, it was suggested that the rotation could be extended.

Keywords: teak, private plantation, smallholder, financial analysis, profit

Introduction

In the past, teak (*Tectona grandis* L. f.) wood of Thailand played an important economic role in timber supply and the wood products for domestic market as well as international market. Thailand forest cover has been decreasing drastically resulting in logging ban in terrestrial forest in 1989. Since then, Thailand turned to be log consuming country instead of producing country. Thailand imported logs and wood products from neighboring countries. In 1994, the Royal Forest Department (RFD) initiated a project, so called "Private Forest Plantation Promotion" to support farmers to establish forest plantation, aiming to produce logs and wood products to serve the demands, including for exporting if there was surplus production from domestic use. The project subsidized 3,000 Baht/rai (1 rai = 0.16 ha) to farmer who had participated in the project, within 5 years by releasing the money 800, 700, 600, 500 and 400 Baht/rai from 1st year to 5th year respectively. Teak was the most favorite tree species planted under this project because the price of teak log was more attractive comparing to other tree species. However, forest owners who participated in the project, faced various problems such as poor growth rate, poor site selection, inefficient management knowledge/skill, and low price of small log/first thinning log. Many owners had abandoned their forest plantation.

Those problems restrained force to the expansion of private teak plantation. Many owners of the plantations changed the areas to plant cash crops or other tree species, such as cassava, sugarcane, and rubber plantation etc. Because they supposed that the crops were more profitable, easier to manage and quicker return than teak plantation. Pusudsavang (2002) reported that more than 50% of areas participated to the subsidy project were abandoned, but there were still some forest plantation owners who kept their teak plantation and some even established new teak plantations. The reasons why they still keep the plantations, were high growth rate in their plantations, environmental concern, higher price expected in future, easy and low cost maintenance and so on. Fig. 1 shows an example of private teak plantation.

Teak plantation was long term investment such as 20 or 30 years while the important parts to be considered for

Fig. 1. An example of private teak plantation

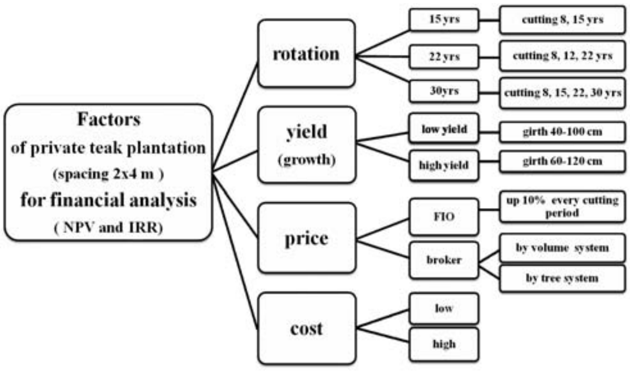

Fig. 2. A framework of financial analysis for private teak plantation investment

profitability calculation were time and interest rate. A key difference between the economic forestry and most agriculture land use was that the financial returns to forestry were often delayed for years (Friday et al. 2000). Therefore, we need to take time value of money into account when planning investment in forest. Financial calculation gave answer to hypothetical question. We have to reply the growth rates, prices and cost particular to our situation (Friday et al. 2000). In forestry, two main economic efficiency indicators were needed and used for different purposes. These were the Net Present Value (NPV) and the Internal Rate of Return (IRR). These indicators had been wildly used in economic analysis (FAO 1979). Discounted Cash Flow (DCF) techniques provided the analytical basis for many forest investment decisions. The comparative financial tool probably most commonly used was Internal Rate Return (IRR) analysis. An IRR was the level of profit expected from an project investment, expressed as an equivalent annual percentage rate of interest on all the money invested in that project (Pandey and Brown 2000). Pitigala and Ganatilake (2002) assessed financial and economic feasibility of selected forest plantation species in Sri Lanka, and found that the NPV of at 10 % discount rate of Mahogany, teak and Eucalyptus resulted in positive, the teak showed the highest financial NPV.

Teak plantation owners need to plan profitable approach for their investment. Profitable calculation depends on yield, log price, time (rotation period) and interest rate. The owners have to clearly understand the use of economic tools to predict the economic return in the future. Therefore, the objective of this study was to analyze factors affecting on private teak plantation investment in smallholder so that the owners could make appropriate decision in the investment.

Materials and methods

A framework of financial analysis for private teak plantation investment was shown in Fig. 2. Data for study was based on 2 sources from reviewing the available data base and interviewing private teak plantation owners including questionnaire survey.

Indices from financial analysis were NPV at 10% discount rate and IRR. We used the set the model of teak plantations as 2x4 m spacing (200 trees/rai), which was popular spacing of private teak plantations. The followings were options by factor:-

1) Rotation periods: 15, 22 and 30 years,
2) Costs of plantation: low and high level,
3) Yields of teak: low and high level, and
4) Prices of teak log in 2 market sources: Forest Industry Organization (FIO) and private broker.

Pusudsavang (2009) showed relationship between teak growth and ages of private teak plantation through the field survey of private teak plantation (Fig. 3). For the yields in the study, we referred to the relationship and defined 2 levels; low and high yields for financial analysis (Table 1). Teak plantation costs were gathered by interviewing the owners on establishment and maintenance costs. The costs were classified into 2 levels; low and high costs for financial analysis. There were 2 market sources of teak selling in domestic market in Thailand, namely, FIO and brokers. Generally the brokers bought teak logs by volume or tree system. The study assumed that the FIO prices were annually increasing at 10% (Fig. 4), while the broker prices were set by volume and tree as current prices in the local market. Thinning of private teak plantation was assumed at 50 % of standing stock of thinning time (Table 2). The rotation periods of private teak plantations were mostly about 20-30 years and shorter than RFD. The study assumed in 3 types of rotations; 15, 22 and 30 years for financial analysis.

NPVs and IRRs were calculated. The discount rate was used 10% for NPV. The NPV is the difference between the present value of benefits and present value of cost. The NPV can be calculated by the following formula:-

$$NPV = \Sigma_{t=1}^{n} \frac{B_t - C_t}{(1+i)^t} \quad (1)$$

where B_t is benefit or income in the year t, C_t is cost in the year t, n is period of year in the rotation, and i is an interest

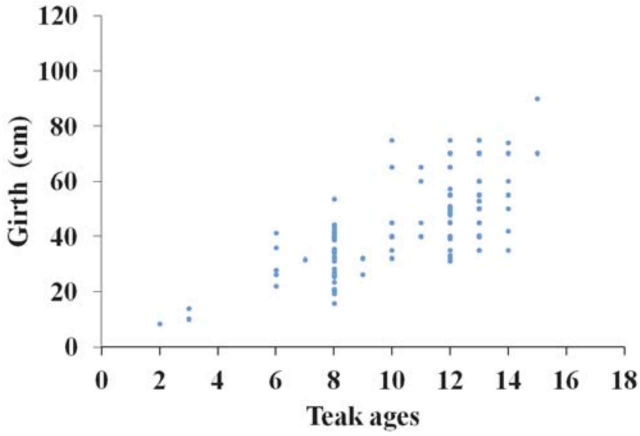

Fig. 3. Relationship between teak growth and ages of private teak plantation
Source: Psudsavang (2009)

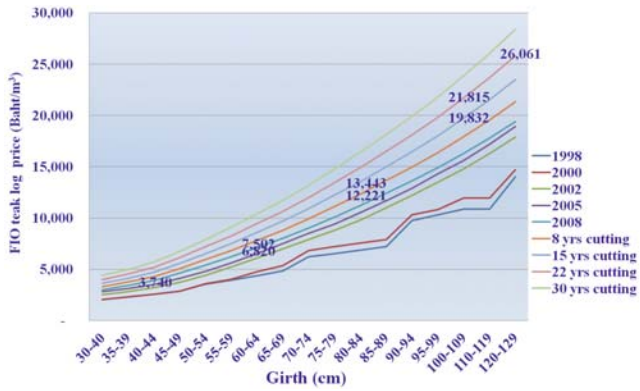

Fig. 4. The prices of FIO teak log (The prices were assumed 10% price increasing in each cutting years)

Table 1. Yield classification by ages of private teak plantation into low and high yields

Level of Growth	Age (year)	Girth size (cm)	Log length (m)	Volume (m^3/tree)
Low yield	8	40	4	0.05
(poor growth)	15	60	6	0.17
	22	80	8	0.41
	30	100	10	0.80
High yield	8	60	4	0.11
(good growth)	15	80	6	0.31
	22	100	8	0.64
	30	120	10	1.15

Table 2. Assigned model of tree cutting and thinning of private teak plantation

Rotation (year)	Purposes of cutting	Cutting year	No of thinning* (tree)	Total no. of tree
15	thinning	8	100	
	final cutting	15	100	200
22	1st thinning	8	100	
	2nd thinning	15	50	
	final cutting	22	50	200
30	1st thinning	8	100	
	2nd thinning	15	50	
	3rd thinning	22	25	
	final cutting	30	25	200

*Thinning ratio 50%.

rate (discount rate).

The positive number of NPV value shows how investment is profitable. If NPV is less than zero or minus, the investment is unprofitable. The IRR is used to estimate the discount rate of return that makes the NPV equal to zero in Eq.1. The IRR can be calculated by the following formula:-

$$\Sigma_{t=1}^{n} \frac{B_t - C_t}{(1+IRR)^t} = 0 \qquad (2)$$

Results and Discussion

1. Teak yields of private plantation

Growth rate of private teak plantation varied from one to others depending on site quality, management and silvicultural practices etc. In first stage of private forest plantation promotion project, most of participating farmers were lack of knowledge such as site selection, silvicultural and managerial practices, etc. The girths and heights at 8, 15, 22 and 30 years of teak plantation were used to calculate the low and high yields. The yields of teak plantation were shown in Table 3.

2. Teak log prices

Thailand had been imported natural teak wood from her neighboring country, Laos and Myanmar, which were very expensive. Recently, the price of teak log ranged from 25,000 to 50,000 Baht/m^3 and prices had continued increasing every year. This provided the private teak plantation logs with an opportunity to compete with teak log imported by wood factories in the country. The teak prices depended on size, age and quality. The private teak plantation logs were mostly ages of 10–20 years or first thinning logs, and they showed small log size and low prices. The private teak plantations were established mostly in small scale areas (about 5–20 rai) and scattered in northern, central and northeastern regions of Thailand.

The teak logs of private plantations were normally sold to brokers at the planting site. The prices ranged from 1,900 to 11,000 Baht/m^3, and were quite low compared with FIO

Table 3. Yield estimation of private teak plantation in 3 rotation periods

Low yield case							
		Rotation (year)					
Cutting year	Volume (m^3/tree)	15		22		30	
		Cutting* (tree)	Yield (m^3/rai)	Cutting* (tree)	Yield (m^3/rai)	Cutting* (tree)	Yield (m^3/rai)
8	0.05	100	5.00	100	5.00	100	5.00
15	0.17	100	17.00	50	8.50	50	8.50
22	0.41			50	20.50	25	10.25
30	0.80					25	20.00
	total	200	22.00	200	34.00	200	43.75
High yield case							
Cutting year	Volume (m^3/tree)	15		22		30	
		Cutting* (tree)	Yield (m^3/rai)	Cutting* (tree)	Yield (m^3/rai)	Cutting* (tree)	Yield (m^3/rai)
8	0.11	100	11.00	100	11.00	100	11.00
15	0.31	100	31.00	50	15.50	50	15.50
22	0.64			50	32.00	25	16.00
30	1.15					25	28.75
	total	200	42.00	200	58.50	200	71.25

* Thinning ratio 50%

Table 4. Teak log prices of FIO and broker at year 8, 15, 22 and 30

Yield level	Cutting year	Girth size (cm)	FIO price* (Baht/m^3)	Broker price (Baht/m^3)	Broker price (Baht/tree)
Low yield	8	40	1,870	1,900	200
	15	60	7,502	3,000	500
	22	80	13,443	6,500	900
	30	100	21,815	8,500	1,500
High yield	8	60	3,410	3,000	300
	15	80	12,221	6,500	700
	22	100	19,832	8,500	1500
	30	120	26,061	11,000	2,000

* The FIO prices were derived from Fig. 4.

teak price. However, the logs could be sold in 3 different ways: 1) log volume (cubic meter), 2) number of standing trees, and 3) area size with standing stock. There were the 3 sources of teak log in markets; natural forest, private plantation and FIO plantation. The teak logs of private plantation were mostly sold to broker or middleman, because of convenience for owners in terms of cutting and transportation process, even if the price was lower than FIO. The FIO was a state enterprise which managed forest plantations, and sets prices of their teak logs by auction. The FIO teak price was comparatively higher than broker price. The prices of FIO and broker were shown in Table 4.

3. Establishment and maintenance costs of teak plantation

The major costs were establishment and maintenance activities which were seedling, planting, weeding, and fire protection. There were different costs of establishing private teak plantation ranging from 1,000 to 10,000 Baht/rai. The average cost ranged from 2,000 to 3,000 Baht/rai. We could say the cost of establishing teak plantation was much different, so this study conducted financial analysis on the plantation in 2 levels; low and high costs. The costs used in the study are shown in Table 5.

Table 5. The cost of establishment and maintenance activities

Year	Cost (Baht/rai) Low cost	Cost (Baht/rai) High cost	Operation or type of cost
1	2,000	3,500	teak plantation establishment (site preparing, planting, seedling and weeding)
2	600	1,200	weeding, fire protection, pruning
3	600	1,200	weeding, fire protection, pruning
4	400	800	fire control, pruning
5	400	800	fire control, pruning
6	200	400	fire control
7	200	400	fire control
8	3,000	5,000	logging, transportation
9	200	400	fire control
10	200	400	fire control
15	3,000	5,000	logging and transportation
22	3,000	5,000	logging and transportation
30	3,000	5,000	logging and transportation

4. Income of private teak plantation

The income of private teak plantation was estimated

Table 6. Income estimation from FIO prices in low and high yield of each rotation periods

Rotation (year)	Cutting year	Girth Size (cm)	Log length (m)	Yield (m^3/tree)	Tree cutting (tree)	Yield (m^3/rai)	Log price (Baht/m^3)	Income (Baht)
Low yield (poor site or management)								
15	8	40	4	0.05	100	5.00	1,870	9,350
	15	60	6	0.17	100	17.00	7,502	127,534
22	8	40	4	0.05	100	5.00	1,870	9,350
	15	60	6	0.17	50	8.50	7,502	63,767
	22	80	8	0.41	50	20.50	13,443	275,582
30	8	40	4	0.05	100	5.00	1,870	9,350
	15	60	6	0.17	50	8.50	7,502	63,767
	22	80	8	0.41	25	10.30	13,443	137,791
	30	100	10	0.8	25	20.00	21,815	436,300
High yield (good site or management)								
15	8	60	4	0.11	100	11.00	3,410	37,510
	15	80	6	0.31	100	31.00	12,221	378,851
22	8	60	4	0.11	100	11.00	3,410	37,510
	15	80	6	0.31	50	15.50	12,221	189,426
	22	100	8	0.64	50	32.00	19,832	634,624
30	8	60	4	0.11	100	11.00	3,410	37,510
	15	80	6	0.31	50	15.50	12,221	189,426
	22	100	8	0.64	25	16.00	19,832	317,312
	30	120	10	1.15	25	28.80	26,061	749,254

Table 7. Income estimation from broker price in low and high yield of each rotation

Rotation (year)	Cutting year	Girth size (cm)	Cutting (tree)	Yield (m^3/rai)	Log price (Baht/m^3)	Income by volume (Baht)	Broker log price (Baht/tree)	Income by tree (Baht)
Low yield (poor site or management)								
15	8	40	100	5.00	1,900	9,500	200	20,000
	15	60	100	17.00	3,000	51,000	500	50,000
22	8	40	100	5.00	1,900	9,500	200	30,000
	15	60	50	8.50	3,000	25,500	500	25,000
	22	80	50	20.50	6,500	133,250	900	45,000
30	8	40	100	5.00	1,900	9,500	200	20,000
	15	60	50	8.50	3,000	25,500	500	25,000
	22	80	25	10.25	6,500	66,625	900	22,500
	30	100	25	20.00	8,500	170,000	1500	37,500
High yield (good site or management)								
15	8	60	100	11.00	3,000	33,000	300	30,000
	15	80	100	31.00	6,500	201,500	700	70,000
22	8	60	100	11.00	3,000	33,000	300	30,000
	15	80	50	15.50	6,500	100,750	700	35,000
	22	100	50	32.00	8,500	272,000	1500	75,000
30	8	60	100	11.00	3,000	33,000	300	30,000
	15	80	50	15.50	6,500	100,750	700	35,000
	22	100	25	16.00	8,500	136,000	1500	37,500
	30	120	25	28.80	11,000	316,800	2000	50,000

from above yield (Table 2, 3) and prices of each cutting year (Table 4), which were classified in low and high yield, FIO and broker prices and rotation of 15 22 and 30 year. The incomes were shown as from FIO prices in Table 6, and as from broker prices in Table 7.

Table 8. The NPV of private teak plantation investment at 10% discount rate

Factors			NPV (Baht/rai) and IRR (%)		
Price	Cost	Yield	15 years	22 years	30 years
FIO price	high	low	24,489 (25%)	42,464 (25%)	50,254 (24%)
	high	high	97,766 (43%)	129,790 (37%)	133,461 (38%)
	low	low	29,111 (33%)	47,331 (31%)	55,236 (30%)
	low	high	102,387 (52%)	134,657 (49%)	138,443 (49%)
Broker price					
by volume	high	low	6,238 (17%)	15,889 (19%)	17,159 (18%)
by tree	high	low	10,897 (23%)	9,826 (20%)	8,925 (19%)
by volume	high	high	53,230 (36%)	61,911 (34%)	63,072 (33%)
by tree	high	high	20,350 (30%)	20,570 (27%)	18,543 (26%)
by volume	low	low	10,859 (25%)	20,755 (25%)	22,141 (24%)
by tree	low	low	15,518 (34%)	14,693 (31%)	13,906 (30%)
by volume	low	high	57,851 (47%)	66,777 (44%)	68,053 (44%)
by tree	low	high	24,971 (41%)	25,437 (39%)	23,524 (39%)

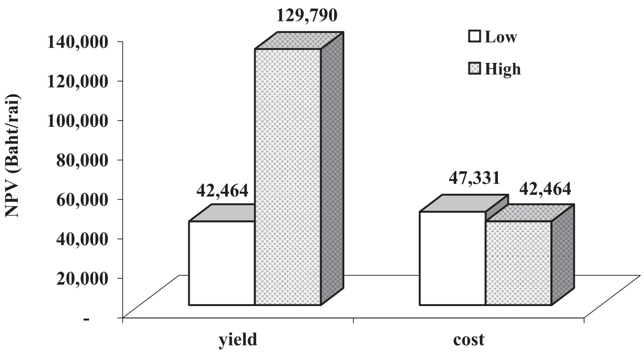

Fig. 5. NPV diagram of yield (high cost case) and cost (low yield) comparison of teak plantation in case of rotation 22 years and FIO prices

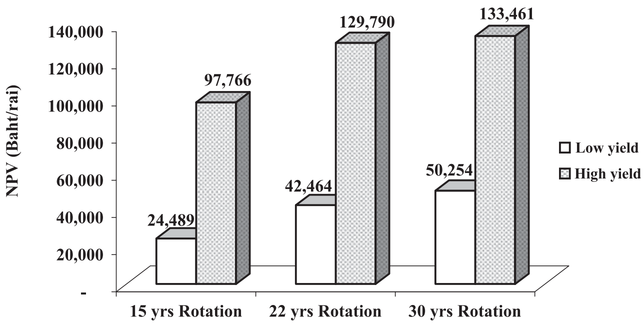

Fig. 6. NPV diagram of comparison rotation of teak plantation in case of FIO prices and high cost

5. Net present value and internal rate of return

The NPVs and IRRs were shown in Table 8. The financial analysis resulted all of NPVs and IRRs were positive, the investments were profitable and varied by the factors. The yields and the prices were main factors affecting teak investment.

NPVs and IRRs were much fluctuated between high and low yield. For example, NPV was 42,464 Baht/rai (low yields) and 129,790 (high yields) under yields in case of FIO prices and high cost (Fig. 5). Thus, the yield factor highly affected investment profit. Such yield is related to mean annual increment (MAI), correspondent to growth rate. The teak plantation owner, therefore, needs to select suitable site.

The cost factors showed a few difference of NPVs between low and high costs. For example, NPV was 47,331 Baht/rai in low cost and 42,464 Baht/rai in high cost, cost factors in case of FIO prices and low yields (Fig. 5). Although the costs increased for pruning and fire protection etc., the costs affected low in teak investment. The owner should pay more attention to yield increasing.

At rotation factors of 15, 22 and 30 years, NPVs and IRRs (FIO prices, high costs and low yields) were 24,489 Baht/rai (25%), 42,464 (25%) and 50,254 (24%) respectively in low yield, and were 97,766 (43%), 129,790 (39%,) and 133,461 Baht/rai (38%) respectively in high yield (Fig. 6). By comparison among the NPVs of 3 rotations, there were big different between 15 and 22 years, but a few different between 22 and 30 years. The profit of 22 years (42,464 Baht/rai) was higher than 15 years (24,489), the rate of increase was 73 % (17,975). But the rate was only 18 %(7,790) between 22 and 30 years. The appropriate rotation should be 22 years among the 3 cases. The yield related to the MAI which varies depending on the site quality, therefore the period of 20-25 years rotation

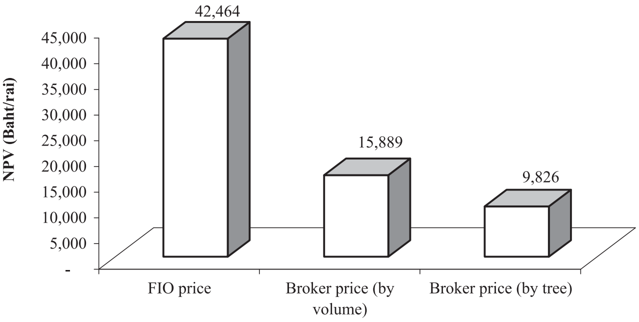

Fig. 7. NPV diagram of FIO and broker prices comparison of teak plantation in case of high cost, low yield and rotation 22 years

could be recommended,

The price factors showed big different values of NPV and IRR between FIO and broker prices. The NPV on FIO prices was higher than broker prices. For example, in case of low yield and high cost, the NPV were 42,464 Baht/rai, and broker prices were 15,889 Baht/rai (by volume) and 9,826 Baht/rai (by tree) (Fig. 7). The broker prices by volume were lower than FIO price, even if teak logs were big (Table 4). The selling price by tree made low profits than by volume. It means that the teak logs prices were depressed by brokers, and the owners might lose profits, especially in terms of selling by tree.

Conclusion

The financial analysis of private teak plantation investment showed effects of factors. The important factors were yield and price. The study tried to provide information which will help investors making decision whether to invest in teak plantation or not. The private sector should know and understand how to use economic tools (financial analysis) in order to assess factors affecting teak investment. The results of financial analysis showed all positive NPV value and profitable. However, it was suggested that owners should compare the profits from other cash crops and species. The price was an important factor for teak plantation owners to make decision on whether to keep their plantation or change to others. Broker prices of teak logs showed much lower level than FIO prices, and generally the selling price by tree produced lower profits than by volume. The private must concern how to get high yield and price. For high yield teak plantation, it needed suitable site or good quality site and good management. MAI was related to the yield factor, and should be taken into consideration. As long as the MAI was continuously increasing, the rotation should be extended. We concluded that the appropriate rotation of teak plantation should be 20-25 years.

In Thailand, the private teak plantation mostly planted in small scale areas scattered over the country, where the broker or middle man took advantage to buy teak log at the plantation sites in very low price compared to general market prices. In order to sell teak log in fair price, local log market should be established. Recently, teak wood from natural forest was decreasing, therefore, teak wood from plantation had potential of replacing the products from natural forest and the price of planted teak wood was also increasing.

Acknowledgements

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Profitability of combined farm management with teak plantations in Northeast Thailand

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Abstract

Farmers want to select a suitable land use pattern for their agricultural land management. Profitability criteria can be useful for decision-making to select a better practice. Teak plantations are said to be highly profitable, but the farmer would have no benefit during the period of time up until teak log harvesting. In this study, we focused on a typical farmer who planted a teak plantation in Nong Bua Lam Phu Province of Northeast Thailand, in terms of land size and land use pattern for crops. The profitability of cash flow models of combined farm management with teak plantation was examined using the equivalent annual income (EAI), among others. The combined approach to farm management improved profitability and mitigated the negative earnings caused by focusing only on teak, and increased the estimated EAIs by 19–315% in comparison with an approach focusing only on teak. In terms of the EAI and benefit/cost (B/C) ratio, the results were 20-year rotation > 15-year, and 4x4 m spacing > 2x4 m. The EAIs were highly sensitive to the log prices at the final cutting age. Second rice allocation was the most important among all crops, and sugarcane and cassava allocations decreased profitability. Thus, producing a higher quality logs at the final cutting age and selecting better land allocation for the combined management approach could effectively improve the level of profitability.

Keywords: teak forest management, land use, farmers, discounted cash flow

Introduction

In Northeast Thailand, some farmers have given up on teak plantations and returned to the cultivation of other cash crops, or chosen to plant other fast-growing tree species. Yokota et al. (2009) and others have pointed out that one of the main reasons for this is that such farmers could not wait for 10 or more years with no benefits until teak harvesting. In terms of farmers' forestry approaches using a valuable indigenous tree species, teak (*Tectona grandis*), in Thailand, Noda et al. (2004) suggested multiple use of their lands, and Yokota et al. (2009) suggested a forest future profit projection method, suitable forest planning, and the adoption of combined farm management with teak plantation to cover the no-profit period before teak harvesting. In addition, Phothitai (1993) and Niskanen (1998), among others, previously studied the profitability of a teak only plantation management approach or its combination with other activities. Niskanen (1998) studied the profitability of teak and cash crop management using agroforestry (intercropping) methods. However, the profitability of combined farm management with teak plantation excluding intercropping systems has not been studied. Therefore, the aim of this study was to compare the profitability of combined farm management with teak plantations and that of teak only plantation management by farmers in Northeast Thailand, and to examine the effects of factors influencing the profitability in order to develop better management practices.

This research was conducted under the RFD-JIRCAS Joint Research Project: 'Development of Techniques for Nurturing Beneficial Indigenous Tree Species and Combined Management of Agriculture and Forestry in the Northeast of Thailand'.

Table 1. The standard costs and benefits for teak plantation management with 15-year rotation in Nong Bua Lam Phu Province

(rotation 15 years, spacing 2x4 m)

Activities	Unit	Year of period														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Survey	man·day	0.5														
Land preparation	man·day	4														
Slash and burn	man·day	4														
Survey road	man·day	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Fire line	man·day	1														
Alignment and Staking	man·day	2														
Planting and seedling transportation	man·day	3														
Weeding	man·day	4	6	6	6	6	6	2	2	2	2	6	2	2	2	2
Fertilizing	man·day	0.5	0.5	0.5				0.5	0.5				0.5	0.5		
Replanting and survival rate checking	man·day	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Pruning	man·day							1	1	1	1		1	1	1	1
Thinning 50%	man·day					5										
Logging	man·day										7					7
Number of seedlings	tree	220														
Amount of fertilizer	kg	100	100	100			100	100				100	100			
Yield	m^3	0	0	0	0	4	0	0	0	0	5	0	0	0	0	8
Yield log price	baht/m^3	0	0	0	0	1,500	0	0	0	0	3,000	0	0	0	0	5,000

(rotation 15 years, spacing 4x4 m)

Activities	Unit	Year of period														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Survey	man·day	0.5														
Land preparation	man·day	4														
Slash and burn	man·day	4														
Survey road	man·day	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Fire line	man·day	1														
Alignment and Staking	man·day	2														
Planting and seedling transportation	man·day	3														
Weeding	man·day	4	6	6	6	6	6	2	2	2	2	6	2	2	2	2
Fertilizing	man·day	0.5	0.5	0.5				0.5	0.5				0.5	0.5		
Replanting and survival rate checking	man·day	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Pruning	man·day							1	1	1	1		1	1	1	1
Thinning 50%	man·day					5										
Logging	man·day										7					7
Number of seedlings	tree	120														
Amount of fertilizer	kg	50	50	50			50	50				100	100			
Yield	m^3	0	0	0	0	3	0	0	0	0	5	0	0	0	0	9
Yield log price	baht/m^3	0	0	0	0	1,500	0	0	0	0	3,000	0	0	0	0	5,000

Source: Royal Forest Department(2006). The data is noted as a case model for Nong Bua Lam Phu Province.

Table 2. The standard costs and benefits of teak plantation management with 20-year rotation in Nong Bua Lam Phu Province

(rotation 20 years, spacing 2x4 m)

Activities	Unit	Year of period																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Survey	man·day	0.5																			
Land preparation	man·day	4																			
Slash and burn	man·day	4																			
Survey road	man·day	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Fire line	man·day	1																			
Alignment and Staking	man·day	2																			
Planting and seedling transportation	man·day	3																			
Weeding	man·day	4	6	6	6	6	6	2	2	2	2	6	2	2	2	2	6	2	2	2	2
Fertilizing	man·day	0.5	0.5	0.5				0.5	0.5				0.5	0.5				0.5	0.5		
Replanting and survival rate checking	man·day	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Pruning	man·day							1	1	1	1		1	1	1	1		1	1	1	1
Thinning 50%	man·day					5															
Logging	man·day										7					7					7
Number of seedlings	tree	220																			
Amount of fertilizer	kg	100	100	100			100	100				100	100				100	100			
Yield	m^3	0	0	0	0	3	0	0	0	0	5	0	0	0	0	5	0	0	0	0	11
Yield log price	baht/m^3	0	0	0	0	1,500	0	0	0	0	3,000	0	0	0	0	5,000	0	0	0	0	7,000

(rotation 20 years, spacing 2x4 m)

Activities	Unit	Year of period																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Survey	man·day	0.5																			
Land preparation	man·day	4																			
Slash and burn	man·day	4																			
Survey road	man·day	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Fire line	man·day	1																			
Alignment and Staking	man·day	2																			
Planting and seedling transportation	man·day	3																			
Weeding	man·day	4	6	6	6	6	6	2	2	2	2	6	2	2	2	2	6	2	2	2	2
Fertilizing	man·day	0.5	0.5	0.5				0.5	0.5				0.5	0.5				0.5	0.5		
Replanting and survival rate checking	man·day	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Pruning	man·day							1	1	1	1		1	1	1	1		1	1	1	1
Thinning 50%	man·day					5															
Logging	man·day										7					7					7
Number of seedlings	tree	120																			
Amount of fertilizer	kg	50	50	50			50	50				100	100				100	100			
Yield	m^3	0	0	0	0	3	0	0	0	0	5	0	0	0	0	5.5	0	0	0	0	12
Yield log price	baht/m^3	0	0	0	0	1,500	0	0	0	0	3,000	0	0	0	0	5,000	0	0	0	0	7,000

Source: Royal Forest Department(2006). The data is noted as a case model for Nong Bua Lam Phu Province.

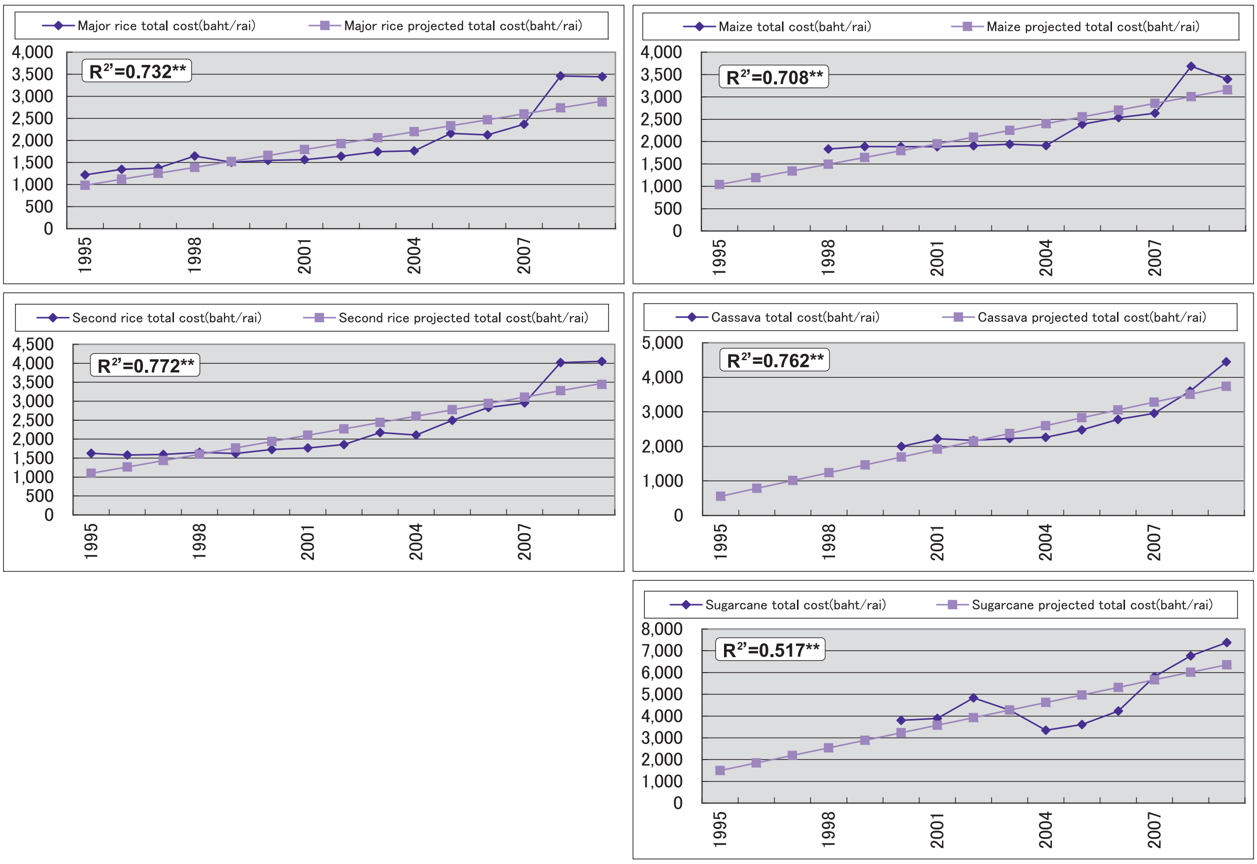

Fig. 1. Cost trend of cash crops in Northeast Thailand. X- and Y-axis mean year and total cost, respectively.

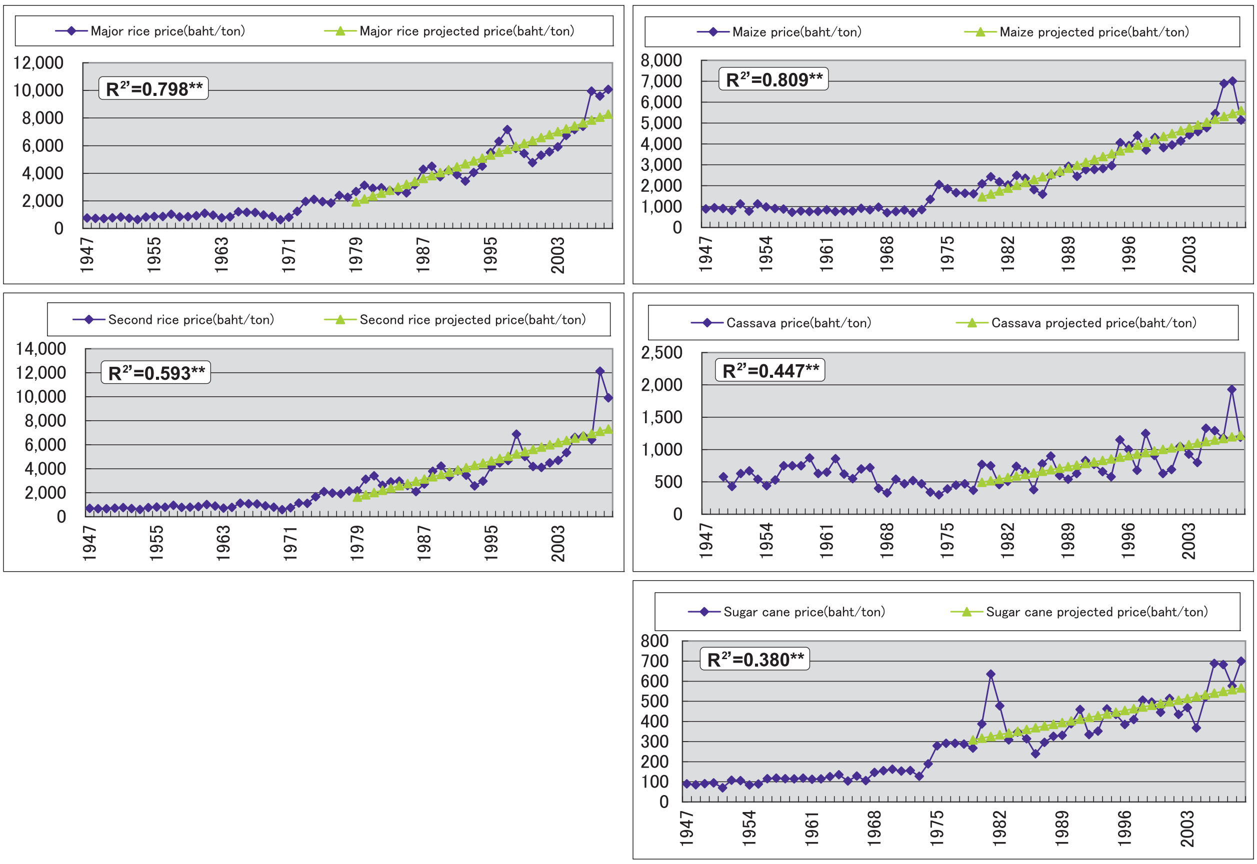

Fig. 2. Farmer's price trends of cash crops in the whole of Thailand. X- and Y-axis mean year and price, respectively.

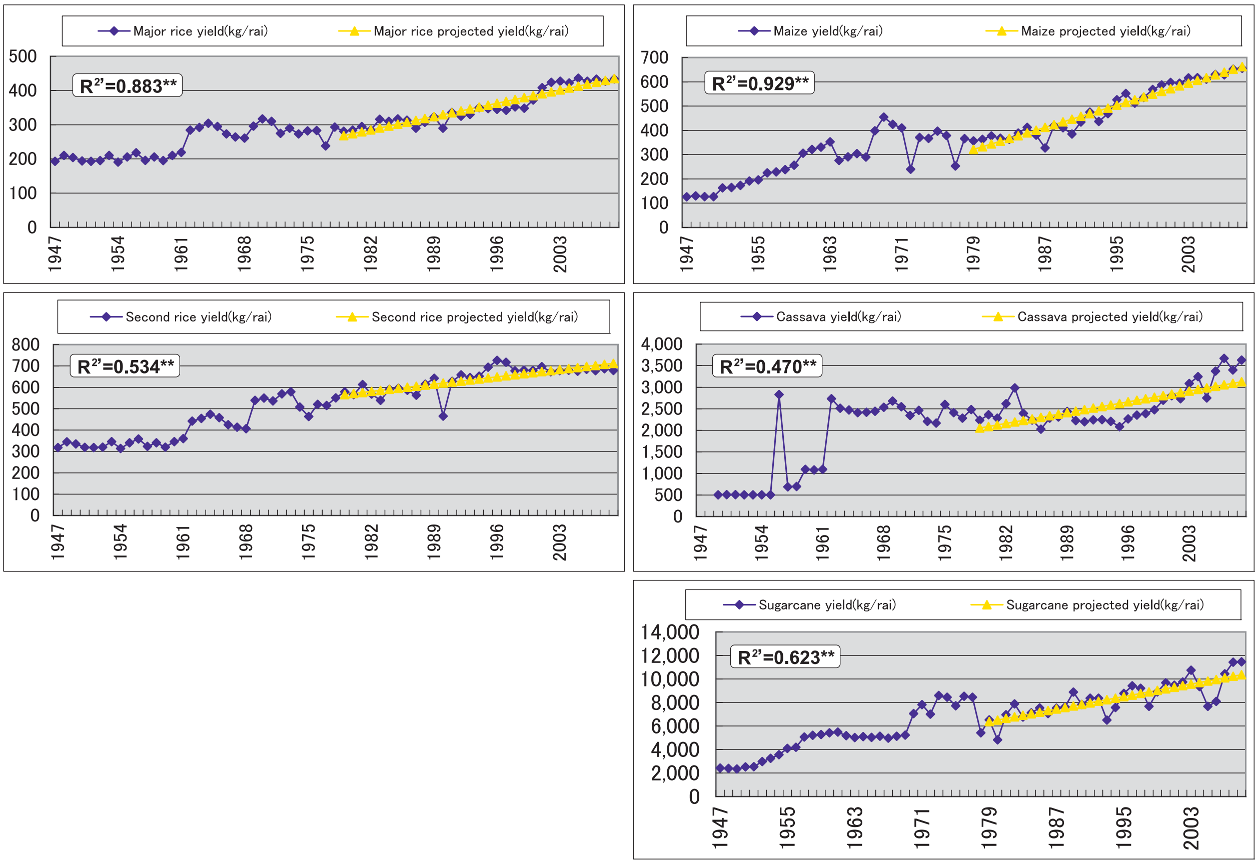

Fig. 3. Yield trends of cash crops in the whole of Thailand. X- and Y-axis mean year and yield, respectively.

Materials and methods

1. Agricultural land allocation pattern

A land allocation pattern in Northeast Thailand was chosen as teak plantation management with the cultivation of typical cash crops such as major rice, second rice, maize, cassava, and sugarcane. We did not include an inter-cropping type. The study site was selected as Nong Bua Lam Phu Province in Northeast Thailand. We assumed a model farmer in the study as one who owned 20 rais of land (1 rai = 0.16 ha) because the mean area of land ownership of farmers is 19.7 rais in Nong Bua Lam Phu Province, according to the Thai Agricultural Statistics 2003 from the Office of Agricultural Economics (OAE). Furuya et al. (2011) showed that the land allocation was 40% for teak, 40% for paddy, 10% for field crops, and 10% for pond & others. Therefore, the model farmland was set with an allocation as follows: teak 8 rais, paddy 8 rais, field crops 2 rais, and pond & others 2 rais. We evaluated management of 18 rais of land, excluding the 2 rais for the pond & others.

In our model, the farmer cultivates major rice on 100% of the area of paddy. As a strict assumption, he cultivates second rice on half of the area of the paddy. This assumption is used because a proportion of farmers may not cultivate second rice. Therefore, in the model, we assumed that the farmland use was teak 8 rais, major rice 8 rais, second rice 4 rais, and field crops (maize, cassava, sugarcane) 2 rais.

2. Cash flow modeling of teak plantation and cash crop cultivation

(1) Teak plantation

We selected the rotation periods of 15 years and 20 years, and planting spacing of 2x4 m and 4x4 m in teak plantation management. The initial establishment, other silvicultural costs, and the benefits from the teak plantation were the same as the standard costs and benefits for reforestation in Nong Bua Lam Phu Province of Northeast Thailand as determined by the Royal Forest Department (2006) (Tables 1,2). For the financial analysis, the unit costs of labor, seedlings, and fertilizer were set at 180 baht/day/person, 5 baht/tree, and 10 baht/kg, respectively, according to the Royal Forest Department (2006).

All of the teak log prices for the study were assumed to be constant and to be free of inflation. For simplicity, administration costs were excluded from the analyses.

(2) Cash crop cultivation

The costs and benefits for cash crops were investigated from statistical data. We conducted regression analyses of production cost, yield ratio, and farmer price, for which the statistical data source was the OAE. As for the annual data

Table 3. Setting assumptions for teak log prices

Log prices	Base value	Range
Log price 20yr-old (baht/m^3)	7,000	6,300-7,700
Log price 15yr-old (baht/m^3)	5,000	4,500-5,500
Log price 10yr-old (baht/m^3)	3,000	2,700-3,300
Log price 5yr-old (baht/m^3)	1,500	1,350-1,650

Source: Royal Forest Department(2006)

used, the production cost was over a 16-year period, 1995-2009, in Northeast Thailand, and the yield ratio and farmer price were over a 31-year period, 1979-2009, in the whole of Thailand. Regression lines of the production cost, the yield ratio, and the farmer price were determined to be significant (R^{2}': adjusted R square. *: p<0.1, **: p<0.05) (Fig. 1-3), and the determination coefficients are shown. We estimated the future annual cost, C, and benefit, B, for the financial analysis using the regression lines, assuming the initial year of the evaluation period as 2010 for the profitability analysis. The C_{it} was obtained by the regression lines of Fig.1, and the B_{it} was obtained by Eq.1.

$$B_{it} = P_{it} \times Y_{it}/1000 \qquad (1)$$

where B_{it} is benefit of cash crop i (baht/rai), C_{it} is production cost of cash crop i (baht/rai), Y_{it} is yield ratio of cash crop i (kg/rai), P_{it} is farmer price of cash crop i (baht/ton), t is the t^{th} year of the management period, and i is a cash crop among major rice, second rice, maize, cassava, and sugarcane.

For cassava and sugarcane, the estimated costs were greater than the estimated benefits for the next 20 years. Therefore, the model farmer should not select cassava and sugarcane as field crops, and his land use would thus be teak 8 rais, major rice 8 rais, second rice 4 rais, maize 2 rais, cassava 0 rai, sugarcane 0 rai, and pond & others 2 rais.

(3) Profitability evaluation

The profitability analyses calculate criteria using discounted cash flow analysis techniques (Price, 1989). The criteria are the net present value (NPV), the benefit-cost ratio (B/C ratio), and the internal rate of return (IRR). For application of NPV, we should select in order of highest NPV from a group of compatible investments (Price, 1989), and can convert NPV to an annual amount called the equivalent annual income (EAI) to compare forestry investment with other land uses for a certain period using the following formula:

$$\mathrm{EAI} = \mathrm{NPV} \times \frac{i \cdot (1+i)^{n}}{(1+i)^{n-1}} \qquad (2)$$

where n is the number of years in the rotation and i is the discount rate (Friday et al. 2000). In this study, we basically used EAI to compare profitability because we have different rotations of investment project period, 20 years vs. 15 years. However, we also determined NPV and B/C ratio. The discount rate for the profitability evaluations was set to 10%.

Firstly, we evaluated the profitability of combined farm management with teak plantation for the model farmland use by rotation year and spacing, and made a comparison between the model farmland use (teak 8 rais, major rice 8 rais, second rice 4 rais, maize 2 rais, cassava and sugarcane 0 rai) and the teak only approach for the same area of 18 rais.

Secondly, the uncertainty associated with log price information and the influences of the selection of the allocated land area were examined with sensitivity analyses and parametric analyses, respectively. The sensitivity of the investment to variation in the input log price was examined using Oracle Crystal Ball 11 (Oracle Corp.) to fit a probability distribution to the log price variables and to run Monte Carlo simulations. A triangular distribution was obtained with maximum and minimum values ±10% of the base value (Table 3). The influence of the selection of the allocated land area to the EAI was also examined using the same software to test each variable independently of the others. Hence, the parametric analysis does not consider correlations defined between the variables, but the spider charts from the parametric analysis illustrate the differences between the minimum and maximum forecast values by graphically representing a curve through all the variable values tested.

Results

1. Profitability of combining farm management with teak plantation

The estimated EAIs of the four cases combining farm management with teak plantation were positive and in the range of 1,088–1,595 baht/rai/year (Table 4). The combined teak management of the cases with 20-year rotation, AL 2044 and AL2024, showed higher EAIs than the cases with 15-year rotation, AL1544 and AL1524. The cases with spacing of 4x4 m, AL2044 and AL1544, showed higher EAIs than the cases with spacing of 2x4 m, AL2024 and AL 1524. This means that AL2044 was the most profitable, with an EAI of 1,595 baht/rai/year, among the four cases. The estimated B/C ratios of the 4 cases were in the range of 1.27–1.40, and the values for the cases with 20-year rotation were higher than those with 15-year rotation; in addition, B/C ratio was higher in the cases with spacing of 4x4 m than in the 2x4 m cases (Table 4). Therefore, the case with 20-year rotation and spacing of 4x4 m was not only the most profitable but also the most efficient among the four cases.

In comparison to the teak only cases, the adoption of a combined approach increased the estimated EAIs by 19–315% (Table 4). The EAI by the adoption of a combined approach with 15-year rotation increased 109 and 315%, and the extent of increase was much greater than the corresponding values of 19 and 34% in the 20-year rotation cases, respectively. The estimated EAI by the adoption of

Table 4. The profitability criteria of the combined farm management and teak only management approaches

Rotation age(year)		20	20	15	15
Spacing		4x4m	2x4m	4x4m	2x4m
Combined farm management	Case code	AL2044	AL2024	AL1544	AL1524
	EAI (baht/rai/yr)	1,595	1,393	1,234	1,088
	B/C ratio	1.40	1.34	1.32	1.27
	NPV (baht/rai)	13,583	11,860	9,385	8,273
Teak only management	Case code	TK2044	TK2024	TK1544	TK1524
	EAI (baht/rai/yr)	1,337	882	591	262
	B/C ratio	1.70	1.41	1.30	1.12
	NPV (baht/rai)	11,383	7,509	4,495	1,993
Difference between the combined and teak only EAI (baht/rai/yr) and (%)		258(19%)	511(34%)	643(109%)	826(315%)

The discount rate was set to 10 %.

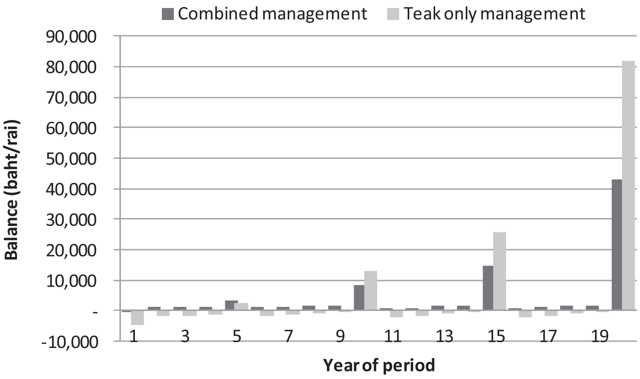

Fig. 4. Comparison of cash flow balances between the combined farm management and teak only in the case with 20-year rotation and 4x4 m spacing

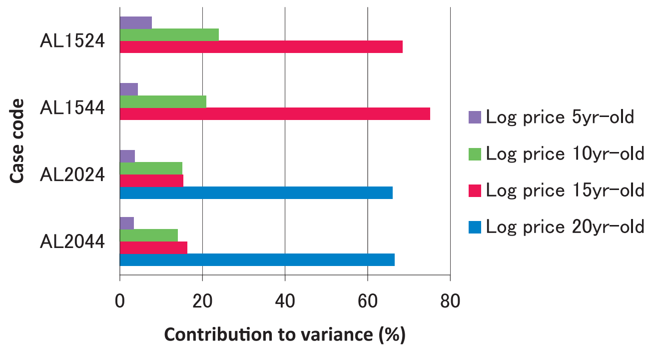

Fig. 5. The influences of log prices on the EAI

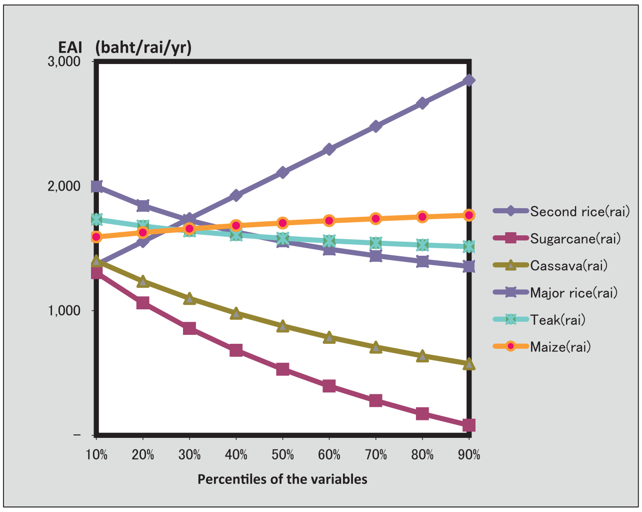

Fig. 6. Relationship between the crop land allocation and EAI by parametric analysis with 20-year rotation and spacing of 4x4 m

the combined approach in the cases with spacing of 2x4 m increased 34 and 315%, and the extent of increase was greater than the corresponding values of 19 and 109% in the cases with 4x4 m spacing, respectively. This means that the adoption of the combined approach increased the EAI the most with 15-year rotation and 2x4 m spacing among the four cases. As for the cash flow balance, the teak only approach showed negative earnings during the periods with no teak harvest (Fig. 4). However, the adoption of a combined approach mitigated the negative earnings.

2. Sensitivity analysis and parametric analysis

The estimated EAIs were highly sensitive to the log prices at the final cutting age in the cases with a combined approach (Fig. 5). The contributions to variance (CTVs) of the log prices at the final cutting age were 66–75%; the CTVs of the log prices at the last thinning age were 15–24%. Younger log prices before final cutting age in general affected less to the EAIs.

The spider chart as Fig. 6 illustrates the differences between the minimum and maximum forecast values by graphing a curve through all the variable values tested, and curves with steep slopes, positive or negative, indicate that those variables have a large effect on the forecast (Gentry et al. 2005). The spider chart showed that second rice allocation had the steepest positive slope, that is, the highest sensitivity ranking, and is the most important among all six variables (Fig. 6). The sugarcane and cassava allocations had the steepest negative slopes, that is, a large negative effect on the EAIs. The major rice and teak allocations had mild negative slope and showed little effect on the EAIs, while the maize allocation showed little positive effect.

Discussions

In this study, the assessed IRRs for the teak only approach were 16.6% in TK2044, 14.1% in TK2024, 14.2% in TK1544, and 11.8% in TK1524. Niskanen (1998) concluded that the estimated financial profitability of reforestation in Thailand was high, and showed that the estimated IRRs and financial land expectation values (LEV) of industrial (MAI 10 m^3/ha/year) and community-based (MAI 7.5 m^3/ha/year) teak reforestation options with 25-year rotation in Thailand were 19.0 and 17.4% and 99,974 and 70,594 baht/ha/year, respectively, with a 10% discount rate. The LEV can be converted to EAI using the following formula:

$$\mathrm{EAI} = i \times \mathrm{LEV} \qquad (3)$$

where i is the discount rate (Friday et al. 2000). The EAIs are equal to 1,600 and 1,130 baht/rai/year, respectively. The profitability of TK2044 was close to and intermediate between the intensive and extensive teak management EAIs with 25-year rotation (Table 4), and the situation could be considered proper.

Farmers' net cash benefits from agriculture were 22,085 baht/household/year in Northeast Thailand and 19,920 baht/household/year in Nong Bua Lam Phu Province, according to the Thailand Agricultural Statistics 2005 (OAE). The amount of net cash benefits from agriculture would be 28,710 baht/household/year for AL 2044, 25,074 for AL2024, 22,212 for AL1544, 19,584 for AL1524, 24,066 for TK2044, 15,876 for TK2024, 10,638 for TK1544, and 4,716 for TK1524 from each EAI. The model farmer would have equivalent or more net cash benefits than the mean farmers' net cash benefit from agriculture, if he was to adopt one of AL2044, AL2024, AL 1544 or TK2044.

The case with 20-year rotation and spacing of 4x4 m was the most profitable and efficient among the four cases. The estimated EAIs of combined farm management with teak plantation varied between 1,088 and 1,595 baht/rai/year. The estimated profitability of the combined farm management with teak plantation was higher than that of the teak only approach for the same area. Thanks to the change from a teak only plantation to a combined approach with teak plantation, the EAI increases in the cases with 15-year rotation can be expected to be much greater than those in the cases with 20-year rotation. According to the results, it would be recommended that the farmer selects the combined farm management approach with teak

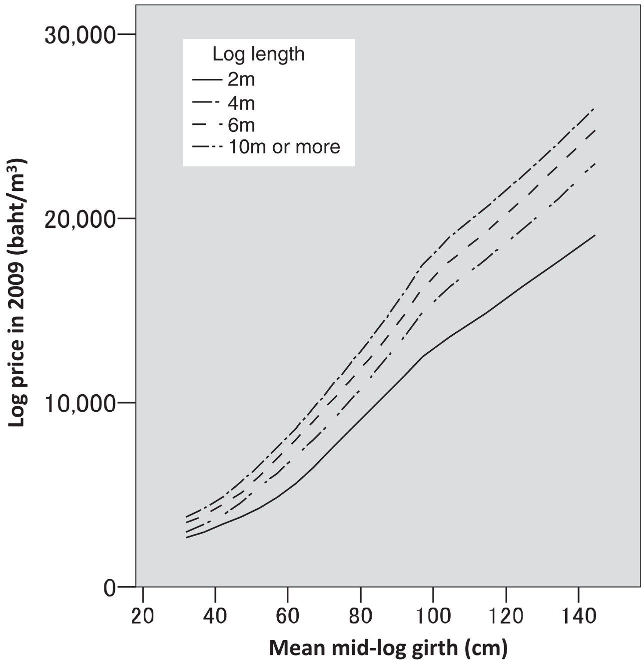

Fig. 7. Price-size relationship in teak log standard prices of FIO. Data source was FIO standard price table in 2009.

management, and not selects a teak only approach; in addition, 20-year rotation should be preferable to 15-year rotation for the teak plantation management approach. If the farmer wants a final-cut income early and selects 15-year rotation, he would be strongly recommended to select the combined approach with teak plantation. Because he could expect much more annual income compared to teak only approach.

The log price at final cutting age was a very influential factor for the EAIs. The farmer could effectively increase the profitability of EAI by making efforts to produce higher-quality logs at the final cutting age as much as possible. Such quality refers to large diameter and heartwood ratio, straightness, and fewer branches, among others, which all affect the log price level. For example, a farmer who applied 20-year rotation would be better off targeting the production of high-quality logs at 20 years rather than thinning logs at 15 years or 10 years.

The price-size relationship has great significance in harvesting and silvicultural decisions (Price 1989). The decreasing gradient of the curve as volume increases, which reflects the facts that increasing size eventually secures no more advantageous markets, and that economics of dealing with larger sizes are gradually exhausted (Price 1989). Fig. 7 shows the price-size relationship for teak plantation logs of the Thailand Forestry Industry Organization (FIO). The curve was calculated from the FIO teak plantation log pricelist. The FIO is the biggest supplier of teak plantation logs in Thailand, and the FIO log price generally becomes the standard price of teak plantation logs (Noda et al. 2011). The curves show a slight decrease of gradient at around 100 cm mid-log girth, and also show a mostly linear relationship between price and mid-log girth. The girth refers to that without bark in accordance with an FIO rule. Therefore, growth that increases the thickness is preferable to increase log price, and it could be a target to produce logs of 100 cm mid-log girth without bark.

A larger proportion of heartwood is preferred by end users, and can increase the log price. Okuyama et al. (2005) concluded that the formation of heartwood depends on the tree diameter, that is, the proportion of heartwood of young trees increases abruptly up to 90% at a diameter of around 20 cm, as determined from teak logs from plantations in India, and West and Central Java. They also concluded that maturation age of planted teak was around 12-15 years on the basis of the density and microfibril angle distributions across the stem. It may be necessary to confirm such findings in Thai teak plantation timber. However, the rotation age should be at least 15 years, and a diameter over 20 cm could be a key to get a larger proportion of heartwood in order to increase log prices.

From the parametric analysis, we could find a more profitable farmer's land use pattern using the spider chart; this was the case of AL2044, with a new land use pattern of teak 8 rais, major rice 8 rais, second rice 8 rais, maize 2 rais, cassava 0 rai, and sugarcane 0 rai, which revised the EAI by 26%, up to 2,007 baht/rai/year, with the same effect on the B/C ratio at 1.40.

Conclusions

The profitability of combined farm management with teak plantations and that of teak only plantation management was compared. The results showed that a farmer was recommended to select the combined approach with teak management. In addition, 20-year rotation should be preferable to 15-year rotation for the teak plantation to expect higher profitability. If the farmer selects 15-year rotation, he would be strongly recommended to select the combined approach with teak plantation. The farmer should pay attention to produce higher quality logs at the final cutting age. It could be a target to produce teak logs of 100 cm mid-log girth without bark in the teak management. A better land use pattern for the combined management approach could effectively improve the level of profitability. However, the optimal land allocation for cash crops would be necessary to be studied in terms of the profitability of combined approach.

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