BMEL-ITTO Project:
"Enhancing Conservation and Sustainable Management of Teak Forests and Legal and Sustainable Wood Supply Chains in the Greater Mekong Sub-region"

ITTO-TEAK IN MEKONG

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ITTO-TEAK IN MEKONG

Field Training in Silvicultural Practices

Tosporn Vacharangkura

Technical Report

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Technical Report

FIELD TRAINING IN SILVICULTURAL PRACTICES

By

Tosporn Vacharangkura

ITTO-TEAK IN MEKONG

BMEL-ITTO Project:

"Enhancing Conservation and Sustainable Management of Teak Forests and Legal and Sustainable Wood Supply Chains in the Greater Mekong Sub-region" (PP-A/54-331)

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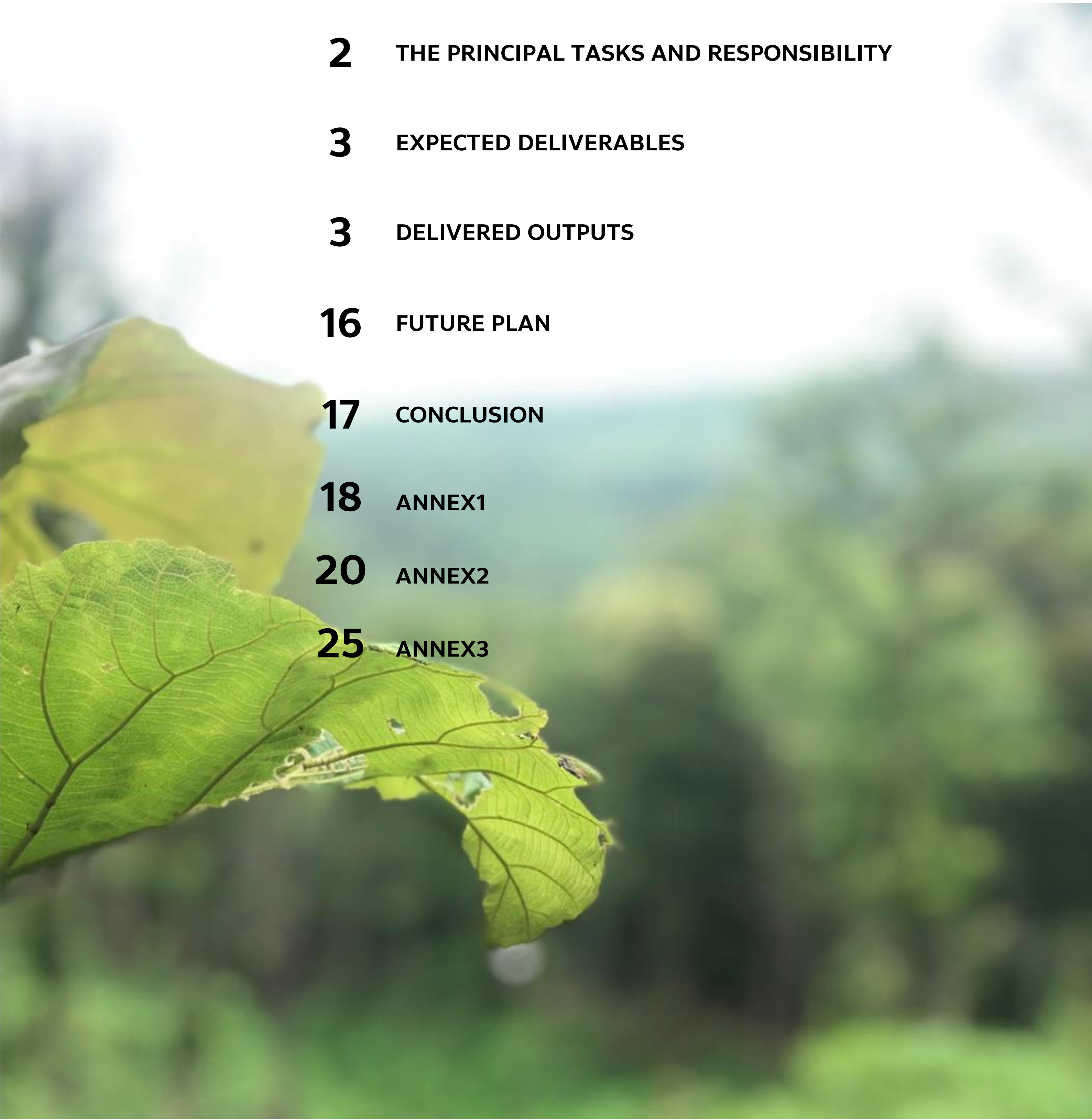


BACKGROUND

The International Tropical Timber Organization (ITTO) Japan launched project on sustainable teak management in Greater Mekong Sub-region entitled "**Enhancing Conservation and Sustainable Management of Teak Forests and Legal and Sustainable Wood Supply Chains in the Greater Mekong Sub-region**" (**PP-A/54-331)**, was approved by the 53rd International Tropical Timber Council Meeting held in Lima, Peru in November 2017. At the 53rd ITTC session, the Council approved an activity entitled "*Enhancing Teak Management*" under ITTO Biennial Work Program (BWP) for 2018-19 with the budget of USD 1,236,250 financed by the Federal Republic of Germany through the Federal Ministry of Food and Agriculture for implementation in 5 Mekong countries namely, Cambodia, Lao PDR, Thailand, Vietnam and Myanmar. The duration of the project is 3 years from March 1, 2019 to September 30, 2022.

The objective of the Project is to assist governments, local communities and smallholders to enhance natural teak forest management, production and marketing to facilitate the establishment of legal and sustainable teakwood supply chains while improving local economy and local communities' livelihood in the Mekong sub-region (GMS). The project expects 3 outputs: 1) to enhance the conservation, sustainable management and use of teak ,genetic resources of natural and planted teak forests and market access of teak from legal sources have been shown, 2) Community-based smallholders teak forest management and agroforestry systems have been strengthened with improved legal and sustainable supply chains, and 3) to strengthen regional and international collaboration, information sharing and knowledge management, networking, policy development and outreach on the sustainable management of natural and planted teak forests and sustainable use of teak genetic resources.

Natural teak forests covering an area of about 29 million hectares occur in central and southern India, Lao PDR, Myanmar and Thailand. Myanmar has the largest area of natural teak forests (almost 16 million ha) and is the number one producer of natural teak logs in the world. Thailand has the second largest area of natural teak forests (after Myanmar) at an estimated 8.7 million ha, all of which are located in protected areas. The participating countries, viz., Cambodia, Lao PDR, Myanmar, Thailand, and Vietnam are located in the GMS. These five participating countries are home to more than 300 million people. It is a very dynamic and fast-changing region that has made significant socio-economic progress since 1990 resulting in significant impacts on natural forest resources.

In order to implement the ITTO Teak Project in Mekong effective, the **Consultant#5: Field Training in Silvicultural Practices** was recruited to take responsibility to support local communities and smallholders of teak plantation through series of training sessions and field demonstration and field training on silvicultural practices and improved stand management.

THE PRINCIPAL TASKS AND RESPONSIBILITIES

The principal tasks of the **Consultant# 5 Field training in silvicultural practices** are to support local communities and smallholders through establishment of demonstration plots and field training on silvicultural practices and improved stand management. Participants in the training sessions are mainly from Thailand and a few members are invited from the participating countries, namely Cambodia, Lao PDR, Myanmar, and Vietnam.

The specific functions and responsibilities include:

- Prepare a program for five-day group training, including classroom presentations/discussions and field training on silvicultural practices and stand improvement that is tailored to the needs of smallholder teak plantation and relevant teak stakeholders and has the objectives to improve the efficiency of teak plantation establishment, stand growth and stand quality after plantation establishment.
- Include in the training programs the following subjects 1) teak plantation establishment, 2) intermediate silvicultural practice like thinning and pruning practices, 3) agroforestry practice, and 4) high quality seedling production and mother-tree selection (work with consultant# 2).
- Implement the training program once a year during the activity period (total three times).
- Present the activity outcomes, results and findings to the Project Technical Committee (PTC)
- Incorporate comments provided by the PTC members and stakeholders in the final report.
- Compile all results and findings of each training event, incl. recommendations for follow-up actions, in a technical activity report in English language to be submitted to the Regional Activity Manager.
- To be available to provide recommendations and advises to National Coordinators, PTC members (if any).
- Undertake national and international travels, as and when required

EXPECTED DELIVERABLES

The consultant submitted the following outputs to the Regional Activity Manager:

- A general training programs on the assigned topics, target audiences for each training session.
- Training material on silvicultural practices, improved stand management and agroforestry system and applications
- Training reports (1 month after completion of each session)
- Final report
- Technical note for publishing via TEAKNET

DELIVERED OUTPUTS

Summary of delivered outputs of consultant #5 during the reporting time (April 2019 – Oct 2021) include:

Year	Tasks
2019	1. Surveyed and identified potential sites in Lampang and Phayao provinces to establish the demonstration plots. 2. Prepared and conducted "Training Workshop on Teak Propagation Technique and Silvicultural Practice", 5-9 August 2019, Lampang Province 3. Attended Regional Workshop on Sustaining Teak Forests in Mekong Basin, 24-27 September 2019, Yangon, Myanmar. Presented paper entitled "Effects of First Thinning on Growth and Stem Form of Teak Plantation in Thailand"
2020	1. Attended The 2nd Project Steering Committee Meeting and the National Teak Forum in Lao PDR, 18-20 February 2020, Vientiane and Luang Prabang, Lao PDR 2. Published Policy Brief on **"Thinning: an important management tool for smallholder teak plantations"** in Teak Mekong Newsletter April, 2020 - Volume 2(2) 3. Monitored the progress of clonal test of teak (3rd generation) at Mae Ka Silvicultural Research Station, Phayao Province, provided recommendation and advice to the chief of the station on how to produce good-quality seedling from selected clones that will be planted in the clonal test plots at 3 different sites in Thailand. (Funded by ITTO Teak in Mekong). Monitored the progress of high-quality seedlings allocated to smallholders at Ngao Silvicultural Research Station, Lampang Province.

4. Provided a brief lecture on thinning and pruning operation in teak plantations to the trainees who attended the Workshop on the establishment of teak smallholders networking at demonstration plot (Mr. Suchart Poolkerd's private teak plantation at Hang Chat district, Lampang province. Consultant#5 and trainees also shared knowledge and experience in teak plantation establishment and management.

2021 1. Prepared to conduct "Workshop on Mother Tree Selection, Seed Orchard Establishment and Agroforestry" on Feb-Mar,2021 (worked with consultant #2). The workshop was postponed due to Covid-19 pandemic.

2. Preparing a book chapter related to effects of first thinning operation for book entitled **"Sustainable Management of Teak *(Tectona grandis)* in the Mekong Region"** (already submitted draft of the chapter).

3. Monitored the progress of the establishment of clonal test plots at Kroeng Krawia FIO Plantation, Kanchanaburi Province (one of 3 different sites of clonal test in Thailand) and provided recommendation and gave advice to the chief of Mae Ka Silvicultural Research Station on how to conduct clonal test plots and to collect and analyze data of clonal test plots.

2022 1. Prepared and conducted Joint Training Workshop on Teak Plus Tree Selection, Seed Orchard Establishment and Agroforestry", 21-25 February 2022, Phayao Province, Thailand. (worked with Consultant#2).

The delivered outputs can be categorized to 3 groups:

1) Training Workshops 2) Presentations and 3) Publications.

1) Training Workshops

Teak is a tropical tree species naturally occurring in India, Myanmar, Thailand, and Lao People's Democratic Republic. It is an important species that supports the main components of the forestry economy because of its natural ability to grow faster and yet, with good quality timber. In 2010, global area of planted teak forests according to various estimates cover between 4.35 to 6.89 million ha (Kollert and Cherubini,2012).

Thailand has established various forest plantations, especially teak, to support the country's changing demand for wood. The first commercial forest plantation in Thailand was established in the North by the Royal Forest Department (RFD) in 1906 by dibbling teak seeds. Since then, conservative and commercial plantations have been established continuously by the government, state enterprises and the private sector resulting in a total area, excluding rubber plantation, of about 942879.15 rai or 150,860.66 ha (Royal Forest Department,2020).

From the late 1900s until recently, the RFD managed most activities in the national forests alone, particularly forest harvesting, nature conservation, watershed management, forest protection and forest plantations. The Forest Industry Organization (FIO) was also involved in forest harvesting and forest plantation development. Other government agencies (for example, the Department of Agricultural Promotion and the Land Development Department) had limited involvement in forestry. Consequently, a number of conflicts arose among the different state organizations regarding the utilization of forest lands. The situation was further aggravated by unstable and vague policies, poor law enforcement, forest encroachment by poor as well as influential people, strong opposition to forest plantation development by non-governmental organizations (NGOs) and poor administration by government organizations. The results of the RFD's and FIO's monopoly were twofold. First, it led to a steady decline in forest cover. Second, it forced out the private sector, which in turn steered clear of investment in forest plantations for decades. (Mahannop,2004)

FIO has been well known as the leading owner of commercial forest plantations in Thailand. FIO set up a reforestation plan in 1967 to grow teak, with 160 ha per plantation unit, using a rotation length of 60 years (nowadays rotation length changes to around 30 years). However, the first ten forest plantations were started in 1968 in the North (Thaiutsa,2008). The total area of FIO's planted forests established from its beginning, up until the year 2020 was 175106 ha (including rubber plantation). Teak comprises about 53.54% of total plantation area or precisely 93,751.75 ha (Subwilai,2021).

The afforestation in Thailand has also been carried out by private sectors for more than 40 years. Teak (Tectona grandis), Pinus spp., Casuarina spp., Eucalyptus spp. and Acacia spp. are the main tree species selected for afforestation. In 1994, RFD initiated project, so called "Private Forest Plantation Promotion' to support farmers to established forest plantation, aiming to produce logs and wood products to serve the demands, including for exporting if there was surplus production from domestic use. 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. According to the data from Private Plantation Division, RFD the planted teak forest area in this project during 9 years period (1991-2002) was 916,671 rai or146,667.36 ha (Royal Forest Department,2004) However, the owners of teak plantations in Thailand, now faced various problem such as poor growth rate, unsuitable site selection, inefficient knowledge and skill, and low price of small dimensional log/first thinning log. Some owners had abandoned their teak plantations.

1.1) Joint Training Workshop on Teak Propagation Technique and Silvicultural Practices

A joint training workshop on Teak Propagation Technique and Silvicultural Practice during 5-9 August 2019 was conducted at Elephant Conservation Center, Lampang Provinces. The objectives of joint workshop were 1) to introduce participants the basic genetic improvement of teak and selection of materials for propagation 2) to provide basic principle of plant propagation 3) to train participants on various techniques to propagate teak by using seed and vegetative propagation 4) participants learn principle of teak plantation establishment 5) to introduce the principle of intermediate silvicultural practice for stand improvement, and 6) to train participants the technique of thinning and pruning. Joint training workshop approaches included lecture, practical exercise, discussion, and field demonstration. Forty-two participants attended the workshop. They mostly belong field staffs of the Royal Forest Department (5 persons), Forest Industry Organization (5 persons), followed by private and smallholder teak plantations (20 persons), and officials or smallholders from the remaining 4 participating countries (12 persons).

Lectures on overview of tree improvement, plus tree selection, vegetative propagation techniques of teak were given to participants including training on propagation by cutting technique on the same day. On the 2nd day teak plantation establishment was explained to participants to ensure that they could apply to establish teak plantation effectively. In the afternoon, participant visited Thung Kwian FIO Plantation to see the activities of teak plantation. On the last day an overview of intermediate silvicultural practices were demonstrated. Thinning and pruning techniques were focused to ensure that they could apply to improve growth and quality of teak plantation. Field practices and exercise relevant to thinning and pruning operation were conducted at private teak plantation on the same day.Field practices and field visit at Sobplung plantation, and Thampa Thai National Park Lampang province, participants practiced plus tree selection, where at Maegar Silvicultural Research station they practiced seed orchard management.

Photo 1. Joint Training Workshop on Teak Propagation Technique and Silvicultural Practices during 5-9 August 2019, Lampang Province, Thailand.

Photo 2. Presentation material (PPT) used for lectures on "Teak plantation establishment and intermediate silvicultural practices after establishment"

Training results

A questionnaire was prepared and used to determine the levels of satisfaction and subject understanding of the participants. There are nine questions, namely 1) obtain information prior to the training, 2) lecture on mother tree selection, 3) practice on teak propagation,4) establishment of teak plantations, 5) lecture on intermediate silvicultural practices,6) practice on intermediate silvicultural practices,7) overall training contents,8) training venue and accommodation, and 9) additional knowledge gained. Each question consists of five choices or levels of satisfaction (very good, good, moderate, poor and very poor) The respondents needed to select only one answer that reflects his or her satisfaction.

Level of satisfaction and understanding by training contents and logistic arrangements

Subject	Level of satisfaction/understanding (%)				
	Very good (score 5)	**Good (score 4)**	**Moderate (score 3)**	**Poor (score 2)**	**Very poor (score 1)**
1. obtain information prior to the training	31.81	29.55	25.00	9.09	4.55
2. lecture on mother tree selection and good quality materials	50.00	40.91	2.27	6.82	-
3. practice on teak propagation	43.18	50.00	6.8	-	-
4. establishment of teak plantations	45.45	40.90	6.82	6.82	-
5. lecture n intermediate silvicultural practices	38.64	40.91	20.45	-	-
6. Field practice on intermediate silvicultural practices	43.18	38.64	18.18	-	-
7. overall training contents	52.27	34.09	13.64	-	-
8. training venue and accommodation	56.82	31.82	11.36	-	-
9. additional knowledge gained	52.27	36.36	11.36	-	-

About 60% of the respondents have good or very good satisfaction on training information announcement and logistic arrangement prior to the actual training (e.g. provision of concept note, travel arrangement, communication with the project staff), while 13.5% were not satisfied. Practice on teak propagation was ranked as the highest satisfaction and/or understanding. This is due to the fact that all participants had opportunities to practice how to do root cutting technique and grafting. The lecture on plus tree selection and propagation techniques was ranked as the second highest, but about 7% of respondents ranked this lecture as poor largely because there are a lot of technical terms and 18% of respondents have English language limitations.

About 85% of the respondents were satisfied with the lecture on the establishment of teak plantations (45% ranked it very high, 40% high). This is because the instructor (Mr. Boonlert Srisooksai) presented a lot of case studies from over 30 years experiences in forest plantations, especially teak. About 7% of the respondents classified this lecture as of moderate and/or poor satisfaction. Possibly, because these respondents are from the RFD and FIO who are involved in teak plantations.

The lecture and field practice on intermediate silvicultural practices had similar evaluation levels and ranked the lowest among 5 topics, but the accumulated percentages are close to 80%. However, the participants ranked the satisfaction and understanding level differently. Higher score was given for field practice (43% very good, 38% good) possibly language barriers.

Nevertheless, 52% of the respondents were very satisfied, while 34% were satisfied with this training course. Furthermore, approximately 88% of respondents gained additional knowledge and the training enhances their capacity to perform as a trainer in their home country. For instance, Vietnamese, Cambodians and Laotians were very active during and after the lectures. They always asked questions and share their experiences. The percentage of satisfaction in training venue and logistic arrangement was similar to the knowledge gained item.

1.2) Workshop on the Establishment of Teak smallholder Networking, North of Thailand

The workshop was conducted at Ngao Silvicultural Research Station, Ngao District, Lampang Province during 24-26 August, 2021. Consultant#5 participated in the workshop on August, 24 as a lecturer. Participants visited the demonstration plot (Mr. Suchart Poolkerd's private teak plantation at Hang Chat District, Lampang Province. Consultant#5 provided a brief lecture on thinning and pruning operation in teak plantation and share experiences with participants on teak plantation establishment and improving stand management.

Photo 3. Workshop on teak smallholders networking at demonstration plot
(Mr. Suchart Poolkerd's private teak plantation at Hang Chat district, Lampang Province.

1.3) Joint Training Workshop on Teak Plus Tree Selection, Seed Orchard Establishment and Agroforestry

A joint training workshop on **Teak Propagation Technique and Silvicultural Practice** during 21-25 February 2022 was conducted at PM Place Hotel located at Muaeng District, Phayao Province. The objectives of joint workshop are 1) to introduce participants to basic genetic improvement of teak 2) to introduce participants progress up to date of teak improvement in Thailand 3) to train participants on plus tree of teak 4) to introduce participants to principle of teak seed orchard establishment and management 5) to introduce participants to principle of agroforestry, and 6) to train participants how to apply agroforestry system as an option for teak plantation establishment and management. Joint training workshop approaches included lecture, practical exercise, discussion, and field demonstration. Thirty participants attended the workshop. They mostly belong field staffs of the Royal Forest Department (10 persons), Forest Industry Organization (10 persons), followed by private and smallholder teak plantations (10 persons).

Lectures on basic genetic improvement, plus tree selection, principle of teak seed orchard establishment is provided by Consltant#2 on the 1st day. Consultant#5 gave participants the lectures on principle of agroforestry system including its application for teak plantation establishment and management on the same day. The main topics of agroforestry system and its applications was presented as following.

- History of agroforestry
- Definitions and concept of agroforestry system
- Type of agroforestry system
- Advantages and disadvantages of agroforestry system
- Interaction between trees and agricultural crops in agroforestry system
- Risks of monoculture forest plantation and decreasing risks
- Suitable models of agroforestry system for smallholder farmer
- Application of agroforestry system(models) for teak plantation

On the 2nd day participants visited Mae Ka Silvicultural Research Station. Seed orchard establishment and management and associated activities were presented to participants by Chief of the station (Ms. Somporn Kumchomepoo) to ensure that they understood the procedure of teak seed orchard establishment. Then, Participants went to Ngao Silvicultural Research Station, Ngao District, Lampang Province on the same day. The procedures of seed collection from teak plus tree and seed management were demonstrated to participants followed by field practices on plus tree selection respectively to ensure that participants could do by themselves. On the last day participants visited demonstration plots of agroforestry (intercropping forest trees or fruit trees on agricultural crops cultivations) located on Ban Tam Subdistrict, Muaeng Payao District, Payao Province implemented by Mae Ka Silvicultural Research Station and hilltribe group of Northern Thailand (Lisu hilltribe). Participants learned how to apply agroforestry system as an option to grow teak or other forest trees species with fruit tree (cultivated banana, longan and avocado) and agricultural crops. This system could support hilltribe people for agricultural land without reducing teak plantation area. Participants then went to see a private homegarden in agroforestry system, a small area of 5 rai (0.8 hectare) located on Mae Ka Subdistrict, Muaeng Phayao District, Phayao Province. Homegarden is one of the most prevalent types of land use system suitable to tropical monsoon areas. Participants learned how to raise multistory combinations of various perennial and annual crops for home consumption and sale, sometimes in association with domestic animal around homestead. They could apply this model of agroforestry system as an option for improvement in livelihood through various food production, wood products, fodder and firewood, high biodiversity, low use of external inputs, etc. And then participants went to Ban Tham Subdistrict, Dok Kham Tai District, Phayao Province in order to see experimental plot of intercropping teak (high-quality genetic improved teak) with agricultural crops (implemented by RFD) and private teak agroforestry plots belong to smallholder farmer (Mr. Inthuan Kruaboon). Participants learned layouts of various alley cropping (hedgerow intercropping) plots where teak trees, managed as hedgerows, were grew in wide rows and agricultural crops, such as upland rice, maize, etc. were planted in the interspace between teak rows. Consultant#5 gave participants explanation of the model and shared experiences in the field with them.

Photo 4. Joint Training Workshop on Teak Plus Tree Selection, Seed Orchard Establishment and Agroforestry during 21-25 February 2022, Payao Province, Thailand.

Photo 5. Presentation material (PPT) and posters used for lectures on "Principle of Agroforestry and Applications"

2) Presentations

Consultant #5 participated in this project as following.

2.1) Participated in the Regional Workshop on Sustaining Teak Forests in Mekong Basin at AFoCO Regional Education and Training Center in Yangon, 24-27 September 2019.

Presentation entitled "Effects of First Thinning on Growth and Stem Form of Teak Plantation in Thailand" was given in the regional workshop on sustaining Teak forests in Mekong Basin, during 24-27September2019, Yangon, Myanmar. There were 40 researchers and experts from 14 countries representing universities, policy makers, teak plantation managers, wood industry, international organizations, and NGOs. The regional workshop was designed with six thematic Technical Sessions in focus. The presentation was in Session 2: Sustainable management of teak forests - R&D in silviculture and best practices.The summary of presentation is presented as following.

Thinning has been the major tool in regulating tree growth and improving timber quality. Low thinning is commonly applied to commercial teak plantations in Thailand, especially on the first intervention, however heavy thinning (>50% removal) has shown to reduce the overall productivity of the stands and it may result in the stability of stands at risk. The aim of the case study at a private plantation in Uttaradit Province, Thailand was evaluating the effects of thinning intensity on growth development, yield and stem form of Teak stand. Diameter at breast height(dbh), total height, crown height, stem volume was measured several times: before thinning, just after the treatment and 1 to 4 years after thinning. Results showed that moderate thinned plots (50% removal) allow an increase in the mean basal area and mean stem volume compared to unthinned and light thinned plots (30% removal). Results obtained on annual stand volume increment in the light thinned plots was highest among treatments and statistically different from the unthinned plots. Thinning had a positive effect on stem form. The absolute stem form factor of light thinned plots was significantly different after 3 years compared to unthinned plots and the moderate thinned plots.

The ppt presentation material is attached in Annex 1.

2.2) Participated in the 2nd PSC Meeting and the National Teak Forum in Lao PDR: "Sustainable Teak Value Chains for Sustainable Local Development", Vientiane and Luang Prabang Provinces, Lao PDR on 18-21 Feburuary2020.

Photo 6. 2nd PSC Meeting and the National Teak Forum in Lao PDR: "Sustainable Teak Value Chains for Sustainable Local Development", Vientiane and Luang Prabang Provinces, Lao PDR on 18-21 Feburuary2020.

Photo 7. Presentation on Effects of First Thinning on Growth and Stem Form of Teak Plantation in Thailand in the regional workshop on sustaining Teak forests in Mekong Basin at AFoCO Regional Education and Training Center in Yangon, 24-27 September 2019.

3) Publications

3.1) Policy Brief "Thinning: an important management tool for smallholder plantations in Thailand"

This policy brief was published in Teak Mekong Newsletter April 2020 - Volume 2(2). The contents of this policy brief point out that thinning is probably the most important operation carried out between canopy closer and final harvesting in teak plantation managed for timber production. For most plantation of forest trees, thinning is strongly associated with forest management. The purpose of thinning is to increase economic benefits of plantation stand by increasing growth and improving utilization of wood produced from the stand. However, most smallholder teak plantations in Thailand never considered the benefits of thinning operation of planted teak in their private lands. Their lack of interest is explained mainly by four factors (1) need for maximum short-term economic returns, therefore they want to keep all of the planted trees, (2) smallholders sell timber in the form of trees instead of logs, (3) thinning operation is costly compared with other silvicultural activities, and they cannot sell logs from thinning and (4) forestry laws severely restrict the harvest(thinning and final cuttings) and transport of protected indigenous species.

Photo 8. Policy brief entitled Thinning: an important management tool for smallholder plantations in Thailand.

Nowadays, the Royal Forest Department (RFD) has made an effort to increase forest plantation in private areas to meet the National Forest Policy and the policy of the Ministry of Natural Resources and Environment (MoNRE) by 1) development of forestry industry, and (2) promotion of planting of valuable tree species in ownerships land, that can be cut for sale, and encourage the private sector to invest in forest plantations. A specific strategic issue of the RFD in a period of 20 years, 2017-2036 related to the management of commercial plantation is

"Promotion of Forest Business and Economic forests" in forest planting and community forestry. This consisted of 3 strategies related to thinning operation; 1) promote and support afforestation in economic forests, 2) promote and support the integration and establishment of forest growers, and 3) promote and support of valuable tree species. According to the policies related to the forest strategies as stated above, the RFD has developed management methods for private companies, individual farmers and other sectors. The full article of the policy brief is attached as Annex 2.

3.2) Book entitled "TEAK IN MEKONG FOR A SUSTAINABLE FUTURE"

This book aims at presenting a comprehensive assessment of natural forest management and plantation in the Mekong Sub-region where natural teak forests exist through original articles as well as edited parts of project outputs including research and review papers that have been produced during the course of this project. This book will also provide a window on the recent developments in theory and practices of sustainable teak management in the Mekong region and beyond. The target readers of this edited book include graduate students, scientists, practitioners, private sectors, smallholders and policy makers who are interested in and involved in natural teak forests and teak plantations, wood industry, legality and its related supply chains and environmental management.

This book includes 6 sections.

Section 1: Introduction

Section 2: Teak Distribution Across the Greater Mekong Sub-Region

Section 3: Silvicultural Practices and Teak Improvement

Section 4: Sustainable Teak Forest Management and Certification

Section 5: Research in Teak Genetics

Section 6: Policy and Regional/International Collaboration

Consultant#5 prepared and submitted a draft of one chapter under Session 2 (Teak Distribution Across the Greater Mekong Sub-Region) entitled "*Effects of First Thinning on Growth and Stem Form of Teak Plantation in Thailand*". The full chapter is attached as Annex 3.

CONCLUSION

The **Consultant# 5 Field training in silvicultural practices** conducted two training Workshops: 1) Training Workshop on "Teak Propagation Technique and Silvicultural Practice" was held during 5-9 August 2019 at Elephant Training Center, Lampang Province. and 2) Training Workshop on "Plus Tree Selection, Seed Orchard Establishment and Agro-Forestry" was held during 21-25 February 2022 at PM Place hotel, Muang, Phayao province. Thailand.

In addition, two lectures were presented: 1) Presentation entitled "Effects of First Thinning on Growth and Stem Form of Teak Plantation in Thailand" was given in the regional workshop on sustaining Teak forests in Mekong Basin, during 24-27September2019, Yangon, Myanmar. 2) Participated in the 2nd PSC Meeting and the National Teak Forum in Lao PDR: "Sustainable Teak Value Chains for Sustainable Local Development", Vientiane and Luang Prabang Provinces, Lao PDR on 18-21 Feburuary2020.

Meanwhile, The Consultant#2 also contributed in two articles: 1) Policy Brief "Thinning: an important management tool for smallholder plantations in Thailand" This policy brief was published in Teak Mekong Newsletter April 2020 - Volume 2(2) and 2) An article in the Book entitled "TEAK IN MEKONG FOR A SUSTAINABLE FUTURE" under session 2 (Teak Distribution Across the Greater Mekong Sub-Region) entitled "Effects of First Thinning on Growth and Stem Form of Teak Plantation in Thailand" (Annex3)

REFERENCES

1. Kollert W, Cherubini L. 2012.Teak resources and market assessment.2010. FAO Planted Forests and Trees Working Paper FP/47/E, Rome. Available at http://www.FAO.org/3/a-an537e.pdf. (Accessed December 14 2021)

2. Mahannop Narong.2004. ***The development of forest plantations in Thailand***. *In* What does it take? The role of incentives in forest plantation development in Asia and the Pacific. Thomas Enters and Patrick B. Durst eds. Asia-Pacific Forestry Commission. AP Publication 2004/27.

3. Royal Forest Department. 2004. Data from Private Forest Plantation Division. Available at http://forprod.forest.go.th> research> DETAILS pdf (Accessed December 14 2021)

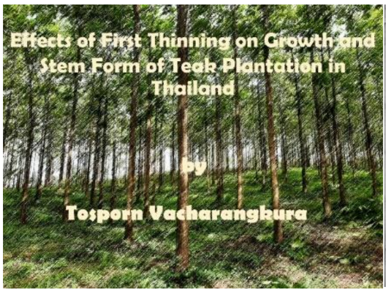
4. Royal Forest Department. 2020. Royal Forest Department 123rd year. Available at cloud.forest.go.th. (Access December 14 202)

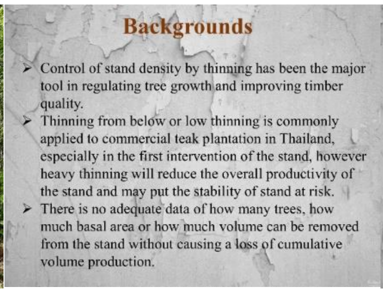
5. Subwilai Patama. 2021. Teak Plantation Certification in Thailand. online presentation in the 3rd monthly Webinar Meeting, ITTO Teak Project in Mekong. Monday, 29 March 2021.

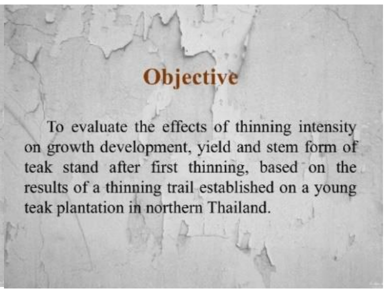
6. Thaiutsa Boonvong. 2008. Commercial Plantation in Thailand: Case Study of the Forest Industry Organization. *In* Proceedings of the FORTROP II: Tropical Forestry Change in a Changing World, 17-20 November 2008, Kasetsart University, Bangkok, Thailand.

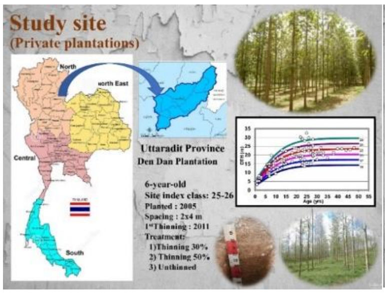
ANNEX 1

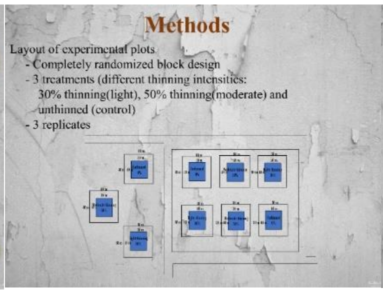
PPT presentation on **"Effects of first Thinning on Growth and Stem Form of Teak Plantation in Thailand."**

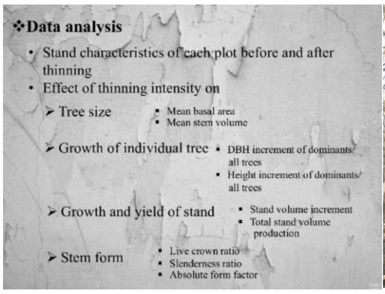


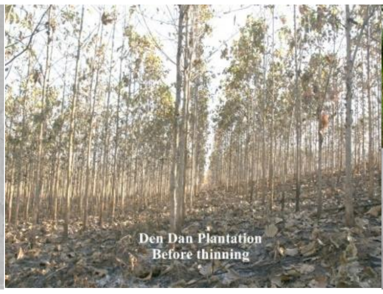


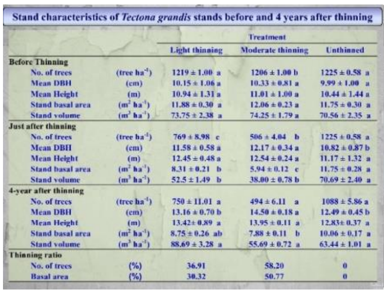






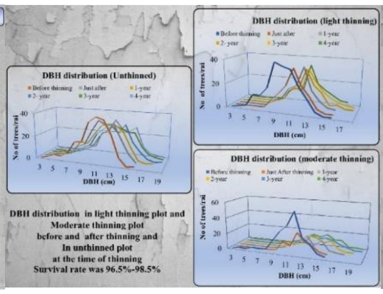


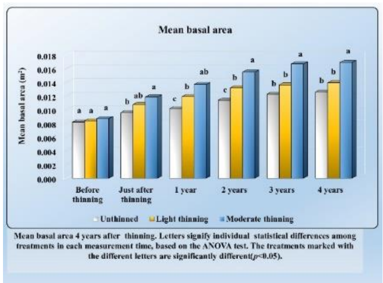


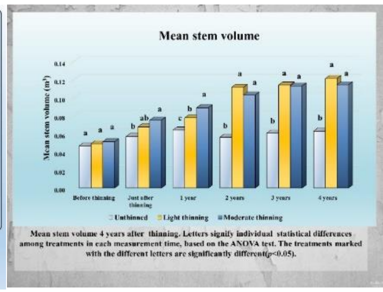


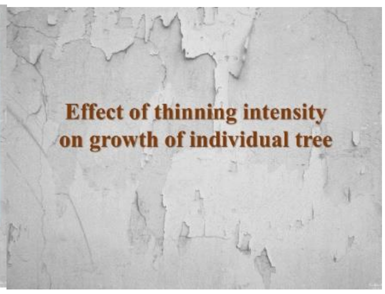
Stand characteristics of *Tectona grandis* stands before and 4 years after thinning

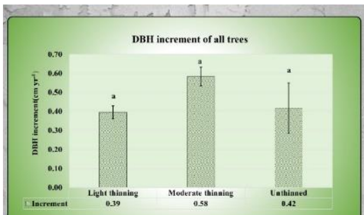
		Treatment		
		Light thinning	Moderate thinning	Unthinned
Before Thinning				
No. of trees	(tree ha^{-1})	1219 ± 1.00 a	1206 ± 1.00 b	1225 ± 0.58 a
Mean DBH	(cm)	10.15 ± 1.06 a	10.33 ± 0.81 a	9.99 ± 1.00 a
Mean Height	(m)	10.94 ± 1.31 a	11.01 ± 1.00 a	10.44 ± 1.44 a
Stand basal area	(m^2 ha^{-1})	11.88 ± 0.30 a	12.06 ± 0.23 a	11.75 ± 0.30 a
Stand volume	(m^3 ha^{-1})	73.75 ± 2.38 a	74.25 ± 1.79 a	70.56 ± 2.35 a
Just after thinning				
No. of trees	(tree ha^{-1})	769 ± 8.98 c	506 ± 4.04 b	1225 ± 0.58 a
Mean DBH	(cm)	11.58 ± 0.58 a	12.17 ± 0.34 a	10.82 ± 0.87 b
Mean Height	(m)	12.45 ± 0.48 a	12.54 ± 0.24 a	11.17 ± 1.32 a
Stand basal area	(m^2 ha^{-1})	8.31 ± 0.21 b	5.94 ± 0.12 c	11.75 ± 0.28 a
Stand volume	(m^3 ha^{-1})	52.5 ± 1.49 b	38.00 ± 0.78 b	70.69 ± 2.40 a
4-year after thinning				
No. of trees	(tree ha^{-1})	750 ± 11.01 a	494 ± 6.11 a	1088 ± 5.86 a
Mean DBH	(cm)	13.16 ± 0.70 b	14.50 ± 0.18 a	12.49 ± 0.45 b
Mean Height	(m)	13.42± 0.89 a	13.95 ± 0.11 a	12.83± 0.37 a
Stand basal area	(m^2 ha^{-1})	8.75 ± 0.26 ab	7.88 ± 0.11 b	10.06 ± 0.17 a
Stand volume	(m^3 ha^{-1})	88.69 ± 3.28 a	55.69 ± 0.72 a	63.44 ± 1.01 a
Thinning ratio				
No. of trees	(%)	36.91	58.20	0
Basal area	(%)	30.32	50.77	0



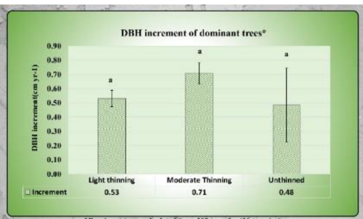






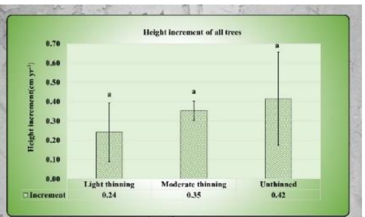


Mean annual DBH increment of all trees. Letters signify individual statistical differences among treatments in each measurement time, based on the ANOVA test. The treatments marked with the different letters are significantly different(p<0.05)

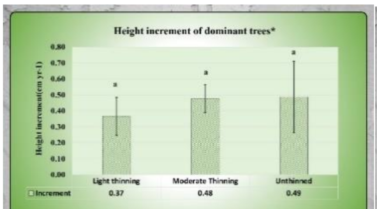


*Dominant trees calculated from 100 trees/ha (16 trees/rai)

Mean annual DBH increment of dominant trees. Letters signify individual statistical differences among treatments in each measurement time, based on the ANOVA test. The treatments marked with the different letters are significantly different(p<0.05)



Mean annual height increment of all trees. Letters signify individual statistical differences among treatments in each measurement time, based on the ANOVA test. The treatments marked with the different letters are significantly different(p<0.05)



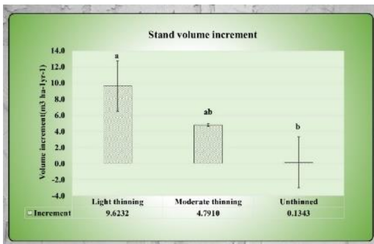
*Dominant trees calculated from 100 trees/ha (16 trees/rai)

Mean annual height increment of dominant trees. Letters signify individual statistical differences among treatments in each measurement time, based on the ANOVA test. The treatments marked with the different letters are significantly different(p<0.05)

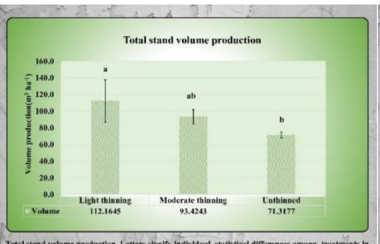
Effect of thinning intensity on growth and yield of stand

Volume production (m^3 ha^{-1})

Treatment	Volume of thinned trees	Volume of dead trees	Current volume production	Total volume production	No. of dead trees (tree)
Light thinning	21.21	2.27	88.69	112.16	46
Moderate thinning	36.77	0.94	55.71	93.42	19
Unthinned	0.00	7.85	63.47	71.32	227



Mean stand volume increment. Letters signify individual statistical differences among treatments in each measurement time, based on the ANOVA test. The treatments marked with the different letters are significantly different(p<0.05)



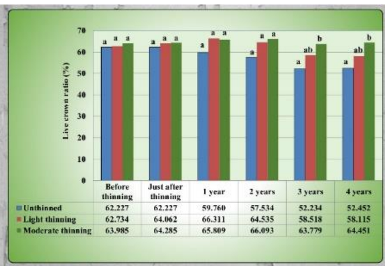
Total stand volume production. Letters signify individual statistical differences among treatments in each measurement time, based on the ANOVA test. The treatments marked with the different letters are significantly different(p<0.05)

% Decrease of annual stand volume increment 4 years after thinning

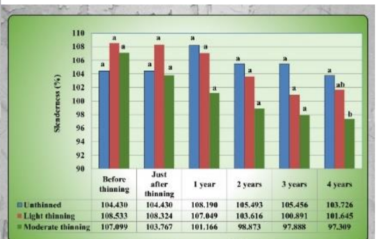
Treatment	Annual stand volume increment (m^3 ha^{-1} yr^{-1}) Just after thinning	4-yr after thinning	*Decrease of annual stand volume increment (%)
Light thinning	12.29	9.62	-22.51
Moderate thinning	12.38	4.79	-64.30
Unthinned	11.80	0.13	-98.86

* Decrease of annual stand volume increment based on unthinned stand

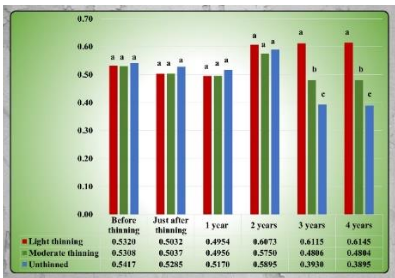
Effects of thinning intensity on stem form



Live crown ratio(%) before and after thinning



Slenderness ratio(%) before and after thinning



Stem form factor before and after thinning

Conclusion

The results of 4 years after thinning operation were concluded that :

Stand structure

The resulting diameter distribution for the number of tree and volume per tree produced a favorable stand structure in the thinned stands and more over thinning prevented regular tree mortality.

Growth and yield of stand

- The total stand volume increment produced per hectare was highest in light thinning plots and differed significantly from unthinned plots, but did not differ significantly from moderate thinning plots.

- The light thinning and moderate thinning intensities reduced the stand volume increment by about 23% and 64% respectively. However, a part of total stand volume production in unthinned plots was lost due to natural mortality.

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Stem form

-The results in this study revealed that thinning had a positive effect on stem form. Live-crown ratio in moderate thinning plots was largest and differed significantly from the unthinned plots.
-The slenderness ratio of trees in the moderate thinning plots was smallest and differed significantly from the unthinned plots. Those ratios was smaller than 100%(97.31%)only in the moderate thinning plots. It meant that the trees in the moderate thinning plots had higher stability than those in unthinned plots.
-The absolute form factor was significantly different among treatments, and unthinned stand gave the smallest; therefore, thinning practice tended to have a positive effect on stem form even in young teak stand.

Thank You

ANNEX 2

Policy Brief
Thinning: the important management tool for smallholder teak plantation

Background

Teak (*Tectona grandis* L.f.) has been one of the most important and valuable tropical hardwood species in Thailand with a long history of plantation started in 1906. Planted teak forests need to be managed following a well-defined operational regime to achieve the desired production goals. Most important are good site selection, use of genetically improved planting material, adequate soil preparation, and the timely execution of silvicultural practices. Protection against forest fire as well as pest and disease management must be effective to avoid losses in productivity. Monitoring growth and yield dynamics is essential to facilitate adequate management responses. Sustainability (social, environmental and economical) including the provision of environmental services (e.g. watershed protection, biodiversity conservation, carbon sequestration) must be a key concern in the management of teak plantation. The implementation of appropriate practices at every stage of development can help to achieve this goal.

Teak is relatively simple to grow in comparison with other commercial hardwood species in Thailand. In teak plantation managed for timber production, thinning is probably the most important operation carried out between canopy closure and final harvesting. However, most smallholder teak plantations in Thailand never considered the potential benefits of planted teak through thinning operation on their private lands. Their lack of interest is explained mainly by four factors: (1) their need for maximum of short-term economic returns, therefore they needed to keep all of planted trees, (2) Smallholders sell timber in the form of trees instead of logs. They generally do not have knowledge, skills and capital to harvest and sell timber directly to wood markets or sawmills. In addition, smallholders' timber tends to be low quality, small in diameter, with knots and other defects and not straight. This is partly because most smallholders do not use appropriate silvicultural practice after plantation establishment, particularly thinning and pruning,(3) thinning operation is costly compared with other silviculture activities they ever did before, but they cannot sell logs from thinning and (4) forestry laws that severely restrict the harvest (thinning and final cuttings) and transport of protected indigenous species.

Why thinning?

In planted forest, after canopy closure, there is intense competition between trees for light, moisture and nutrients. The vigorous trees with the largest crowns become dominant and the weaker trees with smaller crowns become overcrowded and suppressed. Eventually the weaker trees will die, and potential timber production is lost.

Thinning is normally conducted several times during rotation age and must be carefully carried out as the removal of too few trees will result in a greater proportion of smaller diameter trees of limited timber value. Removing too many allows light deep into the canopy resulting in heavy branches and knots, which reduce the quality of the wood and limit its range of potential uses.

In Thailand teak plantation was once managed on rotations more than 30 years, current rotation lengths have been shortened to 30 years or lower from commercial wood plantation. Teak wood from plantation still has not been well accepted in such traditional markets and log prices for plantation teak are much lower than those for old growth natural teak. A major challenge for teak plantation's owner is to develop innovative markets for plantation teak and find uses for low value wood from thinning.

Benefits of thinning

For most plantations of forest trees, thinning is very strongly associated with forest management. It is the practice of removing some trees in an immature stand to increase growth of the remaining trees and the total yield or value of usable wood. Thinning does impacts stand growth, development and structure. It usually implements between regeneration and final harvest, to increase the economic productivity of stands. Thinning can be commercial or non-commercial, depending on objectives of plantation's owner and local market for material cuts in the thinning operation.

The purpose of thinning is to increase economic gain. The gain may be achieved by offsetting the expense of carrying establishment costs to rotation age, increasing the value of the product, and/or increasing stand utilization. Large trees are more valuable than small ones because they are cheaper to transport and the resulting products have a greater value than those from small trees, particularly ones below saw-log size. The beneficial effects of thinning on wood production and utilization are as follows:

Increased growth

Thinning increases the size of individual trees through redistribution and concentration of a site's growth potential on fewer trees. The increased volume growth of individual trees normally occurs as diameter rather than height growth. With a wide range of tree density per unit area, height growth is relatively constant for a given species and site. The primary effect of thinning, therefore, is to increase diameter growth of the remaining trees (Fig. 1). Effective thinning will stimulate this growth within a few years.

Thinned stand

Unthinned stand

Fig. 1 Thinning increases diameter growth: x-section of stem in thinned stand compared with unthinned stand

Many studies have shown that properly managed plantation forests have both economic and ecological benefits. Regular thinning provides an improved environment for maximizing a site's growth potential, which results in larger, healthier trees and more valuable timber. As a silvicultural practice, thinning allows for the continued growth of the healthiest preferred trees in a stand while removing the suppressed, diseased and low-vigor trees that will impede the growth of the entire stand. Many of the low-vigor trees in such stands continue to grow at a reduced rate until they die by severe competition or they are removed by thinning. As a silvicultural practice, thinning concentrates the growth potential of a stand on crop trees and removes suppressed and dying trees. Although stem quality and total utilizable yield may be increased, the effect of thinning may provide marginal economic returns and only limited growth response in the stand over the rotation. (Fig.2) Response to thinning is affected by most of the factors that influence tree and stand growth such as species, age, site index, and stand density

Thinned stand Unthinned stand

Fig. 2 Quality of trees in thinned stand compared with unthinned stand

Improved utilization

While the economic benefits of regularly removing suppressed and dying trees are minimal, intermediate thinning do pay for themselves and provide the economic advantage of improving the health of the entire timber stand. Arranged thinning during growth cycles will yield wood that can be utilized for small pole, joint wood or pellet operations. Again, while the economic gain may be minimal in this case, the health of the overall stand is improved and thus, the value of the overall stand increases.

The other benefits of thinning are to reduce tree damage from disease and insects, genetic enhancement can also be achieved through proper and regular thinning and to perform the better environment of the planted forest. In addition, the proper thinning and controlled burns are the most effective ways to minimize fire exposure.

Wood from thinning

Thinning operations provide timber throughout the rotation. Early thinning from teak plantations are normally sold for lower value end uses due to their small dimensions. Uses include fence posts, wood joints, furniture house furnishings and souvenir, while early thinning. Any revenue generated usually goes into paying for the thinning operation itself, however, material from later thinning is larger and of better quality than that from earlier thinning may yield a degree of profit (Fig. 3)

Fig. 3 Wood products from thinning

Relevant policies and strategies related to thinning

In Thailand, the national forest policy has the important instrument in order to focus on the forest resources management in Thailand. According to the National Forest Policy and the Twelfth National Economic and Social Development Plan (12^{th} plan), commercial forest is targeted at 15% of the country therefore, planted teak forest in the private lands is part of the target area.

Nowadays, the Royal Forest Department (RFD) has made an effort to increase forest plantation in private areas to meet the National Forest Policy and the policy of the Ministry of Natural Resources and Environment (MoNRE) by (1) development of forest industry, and (2) promotion of planting of valuable tree species in ownership lands, and can be cut for sale, and encourage the private sector to invest in forest plantations.

Specific strategic issue of the Royal Forest Department in period of 20 years, 2017 – 2036, related to the management of commercial plantation is Strategic Issue 3: Promotion of Forest Business and Economic Forests in forest planting and community promotion in order to make urban / rural communities to be green areas with 2 purposes: (1) to increase green forest and economic forest outside the forest area, and (2) to increase green area in urban / rural communities.
This consists of 6 strategies, but only 3 strategies are related to thinning operation;

Strategy 1 Promote and support the afforestation in economic forests as follow;
1) Survey and prepare economic forest planting database.
2) Encourage people to plant a forest in their own lands, for forest management, legal regulation, tax deduction, wood purchasing, including innovation.
3) Provide and support funding both short-term and long-term financial sources to various type of economic forest.
4) Provide a number of quality seedlings to growers corresponding to the need and mechanisms of the market.
5) Encourage and export industries that use wood as a raw material for domestic production and export.
6) Transfer technical knowledge to forest economic growers in order to increase productivity and income.

Strategy 2 Promote and support the integration and establishment of forest growers as follow;
1) Promote and support the integration and the establishment of a strong forest grower network.
2) Survey and develop a database of growers.
3) Link forest growers and timber purchase sources for the benefit of forest management services, marketing promotion.

Strategy 3 Promote and support the planting of valuable tree.
1) Study and analyses valuable timber species, including knowledge of planting, maintenance, utilization and marketing.
2) Encourage to plant valuable trees in order to increase the volume of timber in the country.
3) Support to plant valuable trees under the theory of sufficiency economy or agroforestry.
4) Develop techniques to utilize valuable timber.

According to the policies related to the forest strategies above, the RFD has developed management methods for private companies, individual farmers and other sectors.

Recommendations

1. Technical assistance is needed because smallholder teak plantations in Thailand usually do not have much experience or knowledge about silvicultural practices after plantation establishment, especially thinning. They were not familiar with thinning activity, such as the application of

thinning methods and the selection of trees to cut. It was also known that buyers(middleman) set a low price upon trading in teak trees directly with farmer-teak plantations therefore, not only technical assistance in terms of thinning practice but also support and the provision of knowledge on socio-economic aspects were needed. The RFD should provide seminars to the management of teak plantations and also providing information on up-to-date price of teak log to the smallholders.

2. According to Forest Act B.E. 2484 (1941) and subsequent amendment B.E. 2562 (2019) smallholders can harvest teak trees in their lands, but in practical they still have inconvenience to conduct thinning, therefore the RFD, in collaboration with relevant organization should make and effort to improve subordinate legislations, regulations and reduce some of the authorization process regarding thinning operation in order to facilitate and to raise confidence for smallholders who want to conduct commercial thinning.

3. In general, it takes time and money to reach a point where income can be obtained from planted teak forest. Although the efficiency and necessity of thinning have started to be understood gradually, the speed of implementation of thinning was still slow. The RFD, in collaboration with other relevant organizations should discussed the possibility of providing funds for smallholders to conduct thinning and to make them send back the money to source of funds.

4. Aging and labor shortage was considered to be one of the reasons why smallholders, particularly farmer plantations could not conduct thinning. Therefore, there seems to be a potential demand for contract work instead of family labor. The RFD should encourage and support individual smallholders or farmers to form forest-related cooperatives or small-scale community enterprise in order to build a group's strengths. The cooperatives or small-scale community enterprise
has so much potential than individual smallholder to support harvesting and transportation of teak logs. In addition, it has potential to promote fair trade between smallholder and buyers or middleman for selling teak logs.

Additional information

1) NESDB: Office of the National Economic and Social Development Board. 2017. The Twelfth National Economic and Social Development Plans (Plan12th Plan 2017-2021), Development Strategy 4: Strategy for Environmentally - Friendly Growth for Sustainable Development Bangkok, Thailand.

2) The National Forest Policy B.E. 2562 (in Thai).

3) RFD. 2017.The Strategic Royal Forest Department in period 20 years2017 - 2036.Strategic Issue 3: Promote Forest Business and Economic Forests from forest planting and community promotion, urban / rural communities are green areas. Bangkok: RFD. (In Thai).

Chapter 14: Effects of First Thinning on Growth and Stem Form of Teak Plantation in Thailand

Tosporn Vacharangkura

Abstract

The effects of first thinning on growth and stem form of teak stand were examined in Uttaradit Province, northern Thailand. In this study, a randomized complete block design with 3 replications was used and thinning from below (low thinning) was applied as the first thinning. The thinning treatments were as follows: removal of basal area at the level of 0% (control), 30% (light), and 50% (moderate). The measurement period after thinning was 4 years. The results of the study revealed that moderate thinning provided the largest mean basal area and mean stem volume of individual trees in the stands compared with the other treatments. The total stand volume increase in production per hectare was largest in light thinning plots and differed significantly from control plots, but no significant difference was noticed in moderate thinning plots. The light and moderate thinning intensities reduced the annual stand volume increment by 23% and 64%, respectively, related to the mean stand volume increment of thinned stands before thinning was executed, whereas those in control plots reduced by almost 99%.

Part of total stand volume production of control plots was lost through natural mortality. In the thinned plots, natural mortality was considerably low compared to the control plots. The mean diameter (DBH) increment of all trees as well as the mean DBH increment of the dominant trees was enhanced with increasing thinning intensity, but there was no significant difference among the thinned and control plots. However, the mean DBH increment of all trees in control plots was similar to those in light thinning plots. In contrast, total height increment of all trees and the dominant trees were not affected by thinning intensity. Live-crown ratio, slenderness ratio and absolute form factor of the trees in the stand were affected by different thinning intensities. Live-crown ratio increased with greater thinning intensity. On the other hand, slenderness ratio decreased with greater thinning intensity. The absolute form factor was smallest in control plots, and different thinning intensities had clear effects on the absolute form factor. Thus, thinning intensity resulted in improved growth and yield of stands after as well as individual tree size and tended to have positive effects on stem form.

Keywords: Thinning intensity, Mean volume increment, Stand volume increment, Live-crown ratio, Slenderness ratio, Absolute form factor

Introduction

Control of stand density by thinning has been the major tool in regulating tree growth and improving timber quality. Although thinning from below may increase the merchantable volume of a stand, usually it does not increase the total volume increment per unit area (Hasenauer et al., 1997; Zeide, 2001). Many studies have revealed that the stand volume increment of various tree species does not decline with decreasing stand density (Hamilton, 1981; Horne et al., 1986). This indicated that thinning from below (or low thinning) redistributes the increment of individual trees from small trees to larger ones, and a smaller number of trees was able to produce the same volume increment per unit area.

Thinning practice also affects wood properties, such as heartwood proportion, wood density and stem form. Stem form is defined as the rate of taper of a stem. Taper is the decrease in diameter of a stem of a tree or of a log from base upwards. The potential change in stem form as a result of thinning is important with regard to volume and product recovery prediction. Most variation in stem form may be traced to the change in size and distribution of the live crown on the stem and to the length of the branch-free bole (Larson, 1963).

The objective of this study was to relate thinning intensity of the first thinning operation with diameter, height, volume increment and stem form on the basis of permanent long-term experiments with thinning from below (or low thinning) in teak plantation in Thailand. It is an opportunity for us to investigate total stem volume production, thinning removal as well as changes in stem form, during the whole rotation.

Materials and methods

Study site

The thinning trial was established in a private teak plantation at Tha Sao District, Mueang Sub-District, Uttaradit Province, on a site with a tropical monsoon climate, and mountainous region in northern Thailand. The mean annual temperature is approx. 27.7oC with minor daily and annual fluctuations. The annual precipitation is 1,432.6 mm with six dry months. The study site was located at an altitude of 105 m a.s.l., at 17o 41’ 25.5” N, and 100o 17’52.8” E. In an area original cleared for agricultural crops, a 47 rai (7.52 ha) Tectona grandis plantation was established in May, 2005 with initial spacing of 2x4 m (1,250 tree ha-1). The first thinning was conducted in May, 2011 when the teak plantation was 6 years old. The pure teak stand presented canopy closure but severe competition was not evident. The stand basal area was around 1.90 m2rai-1 (11.88 m2ha-1). There was no other silvicultural interventions such as pruning applied to the plantation prior to thinning.

Experimental design and treatments

The experimental design consisted of randomized complete blocks, with three treatments and three replicates. Prior to thinning each treatment consisted of 200 trees. (Including dead trees) in square blocks of 1,600 m2 (20x10 trees under a spacing of 2x4 m),

excluding the buffer zones consisting of two lines of trees, each of them thinned according to the corresponding treatment they were bordering. (Figure 14-1). Thinning from below or low thinning (defined as the thinning method that favors the tallest trees in the stand by removal the lower crown class) with different thinning intensities was applied to each treatment based on the percentage of the stand basal area prior to thinning. The trees removed in each treatment were also selected based on crown class, i.e., dominant, co-dominant, intermediate, and suppressed and also based on characteristics of tree, e.g., no defects, some defects, weak and standing dead. All trees in each thinned stand were divided into five classes and the trees in the fifth class (or the lowest class, i.e., consisting of weak trees, dead trees, and fallen trees) were selected before the others until the target basal area removal in each treatment was reached. The thinning treatments were removal of initial basal area at rate of 0% (unthinned or control), 30% (light) and 50% (moderate).

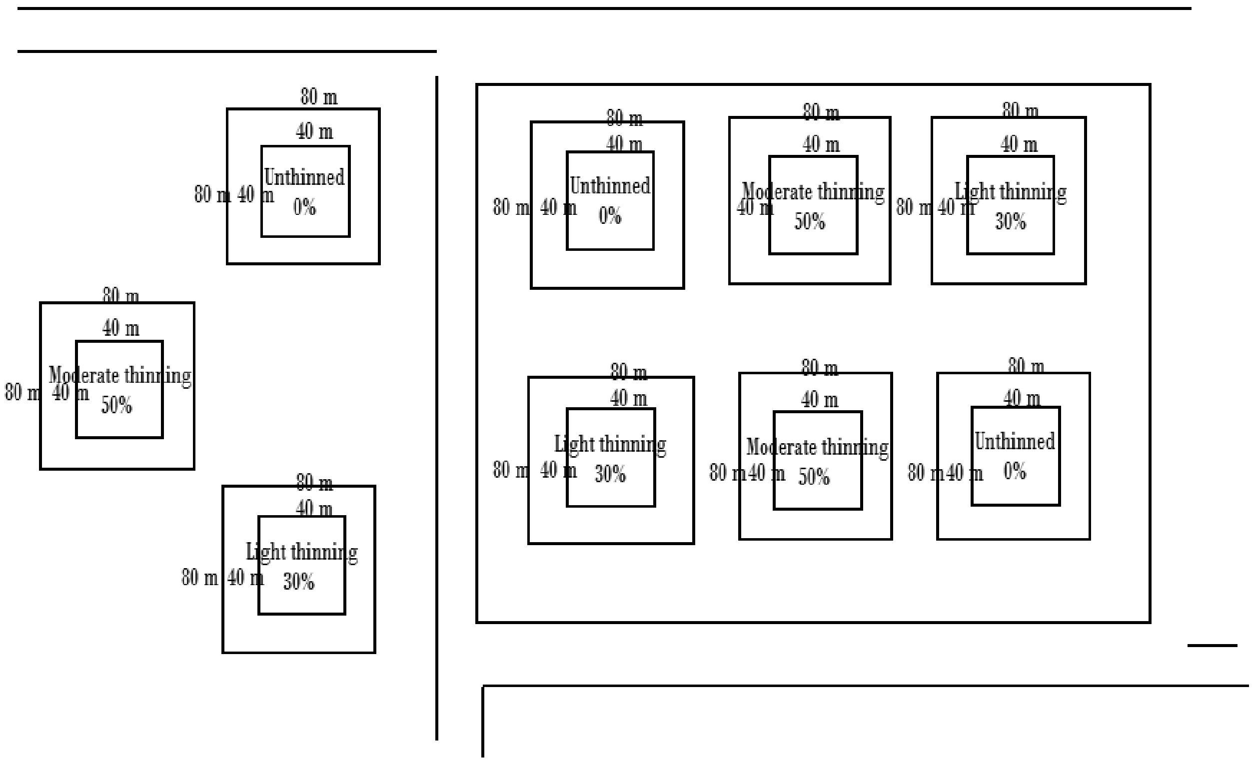


Figure 14-1. Layout of experimental plots

Measurements

Prior to thinning, the experimental plots were measured and re-measured again just after thinning was conducted. Following thinning the tree sizes were measured and surviving trees were surveyed in each plot every year. The measurement period was 4 years. At the time of the last measurement, stand age was 10 years. All living trees in each treatment were numbered and marked at breast height (1.37 m) for annual measurement of stem diameter at breast height (DBH), total height (H), and height to crown base (Hb), using a diameter tape and measuring pole. Digital hypsometer was used when total tree height was more than 15 m.

Two years after thinning, the stem diameter of 10 randomly-selected trees per treatment (control, light thinning and moderate thinning) was measured, using electronic BAF-scope/dendrometer (CRITERION RD 1000). The diameter of a standing tree at target points along the stem and total height of the tree were measured and recorded. The data was used to construct the allometric equation for calculating individual stem volume of trees in each treatment.

Basal area and volume were calculated for each tree and stand total basal area and total volume were calculated by summing the values of all trees in the measurement plot, and then these values were converted to one rai (1,600 m2 or 0.16 ha). The stem volume of each tree was calculated at the thinning time, just after thinning and 1 year after thinning from the stem volume equation for this species presented by Vacharangkura (2001):

V = 0.00009734 DBH1.99583 H0.64695

Where V is the over bark volume (m3), DBH is the diameter at breast height over bark (cm) and H is the tree total height (m).

Because thinning affected stem form (shape) of any tree in stands, different stem volume equations were calculated for each stand with different treatments. The nonlinear model used to calculate individual stem volume was:

V = a(DBH2H)b

Where a and b are constants. Mean basal area and mean stem volume of each treatment were calculated to examine tree size. Annual increment was calculated as the difference between successive measurements divided by the number of years between the measurements. Dominant trees were based on 100 trees by diameter (DBH) of the largest trees per hectare (16 trees per rai). Total volume production and stand volume increment were calculated to examine the effects of the thinning operation.

In order to evaluate the effect of thinning on stem form, the three parameters were applied to investigate the attributes of trees in each treatment at the time before and after thinning was performed. These parameters were:

(1) live-crown ratio (the ratio between crown height and total height (H-Hb)/H)

(2) slenderness ratio (the H/DBH ratio)

(3) absolute form factor (defined as the ratio of the volume of a tree or its part to the volume of a cylinder having the same length and cross section as the tree).

These parameters were calculated for each tree at the time before and after thinning, and then the average in each treatment was used to examine the effect of thinning on stem form.

Statistical analysis

The effects of thinning intensity on tree size, individual growth rate growth rate of stand and quality of stem form were analyzed. ANOVA was applied to examine statistical significant of the differences among treatment. The mean difference comparison, using Tukey HSD were performed to compare the means among treatments. In the tables and figures, the treatments marked with the same letter are not significantly different ($p > 0.05$).

Results

Effects of the thinning on tree size

ANOVA showed that there was no significant difference ($p \geq 0.05$) among treatments in terms of mean DBH, mean height, stand basal area, or stand volume. This means that the plantation had homogeneous structure even though there were slight differences in stand density in the moderate thinning plots compared with the light thinning and control plots (Table 14-1).

Just after thinning, mean DBH was not significantly different between thinned plots, but the thinned plots were different from the control plots. There was no significant difference among treatments in term of mean height. Stand basal area differed significantly in all treatments ($p \leq 0.05$). There was no significant difference in stand volume in the light thinning and moderate thinning plots, both the thinning type plots were significantly different from the control plots. The density of trees differed significantly because of the difference in thinning intensities (Table 14-1).

By the final measurement at 4-year after thinning, the differences in stand density among treatments had changed. There were no significant differences in stand density among treatments because mortality was high in the control plots owing to the severe competition between trees. Mean diameters of the residual stands increased significantly in thinned plots and differed significantly from control plots. On the other hand, there was no significant difference in mean height among treatments. Stand basal area was highest in the control plots (10.06 m2 ha-1) but was not significantly different from plots that had received light thinning. There was no significant difference in stand basal area in all thinned plots($p \geq 0.05$). Four years after thinning, stand volume had increased in all of the thinned plots but decreased in control plots. There was no significant difference in stand volume among the treatments (Table 14-1)

Table 14-1. Stand characteristics of Den Dan plantation before, just after and 4-year after thinning

Before thinning	**Treatment**								
	Light			**Moderate**			**Unthinned**		
No. of trees (tree ha^{-1})	1219	(+1.00)	a	1206	(+1.00)	b	1225	(+0.58)	a
Mean DBH (cm)	10.15	(+1.06)	a	10.33	(+0.81)	a	9.99	(+1.00	a
Mean Height (m)	10.94	(+1.31)	a	11.01	(+1.00)	a	10.44	(+1.44)	a
Stand basal area (m ha^{-1})	11.88	(+0.30)	a	12.06	(+0.23)	a	11.15	(+0.30)	a
Stand Volume (m^3 ha^{-1})	73.75	(+2.38)	a	74.25	(+1.79)	a	70.56	(+2.35)	a
Just after thinning									
No. of trees (tree ha^{-1})	769	(+8.98)	b	506	(+4.04)	c	1225	(+0.58)	a
Mean DBH (cm)	11.58	(+0.58)	a	12.17	(+0.34)	a	10.82	(+0.87	b
Mean Height (m)	12.45	(+0.48)	a	12.54	(+0.24)	a	11.17	(+1.32)	a
Stand basal area (m ha^{-1})	8.31	(+0.21)	b	5.94	(+0.12)	c	11.75	(+0.28)	a
Stand Volume (m^3 rai^{-1})	52.5	(+1.49)	b	38.00	(+0.78)	b	70.69	(+2.40)	a
4-year after thinning									
No. of tree (tree ha^{-1})	750	(+11.01)	a	494	(+6.11)	a	1088	(+5.86)	a
Mean DBH (cm)	13.16	(+0.70)	b	14.50	(+018)	a	12.49	(+0.45)	b
Mean Height (m)	13.42	(+0.89)	a	13.95	(+0.11)	a	12.83	(+0.37)	a
Stand basal area (m ha^{1})	8.75	(+0.26)	ab	7.88	(+0.11)	b	10.06	(+0.17)	a
Stand Volume (m^3 ha^{-1})	88.69	(+3.28)	a	55.69	(+0.72)	a	63.44	(+1.01)	a
Thinning ratio									
No. of tree (%)	36.91			58.20			0.00		
Basal area (%)	30.32			50.77			0.00		

Remarks: BA = basal area
Treatments marked with the different letters in row are significantly different (*p≤0.05*); standard deviation in parentheses

The corresponding basal area and stem volume development of trees in the stands at the time of thinning to 4 years after thinning are presented in Figure 14-2 and Figure 14-3 respectively. The mean basal area in moderate thinning plots was the larger year by year after thinning. At the age of 10 years (4-year after thinning) the mean basal area in moderate thinning plots differed significantly from those in light thinning plots and control plots. There was no significant difference in mean basal area between light thinned plots and control plots.

This result indicated that thinning promoted larger stem diameter in the stands and heavier thinning intensity tended to encourage larger stem diameter of trees. The corresponding mean stem volume of the stands was significantly different among treatments by 1-year after thinning. From 2-year after thinning, the mean stem volume in both light and moderate thinning plots were not significantly different, but were significantly different from the control plots. The results clearly demonstrated that thinning promoted larger tree size.

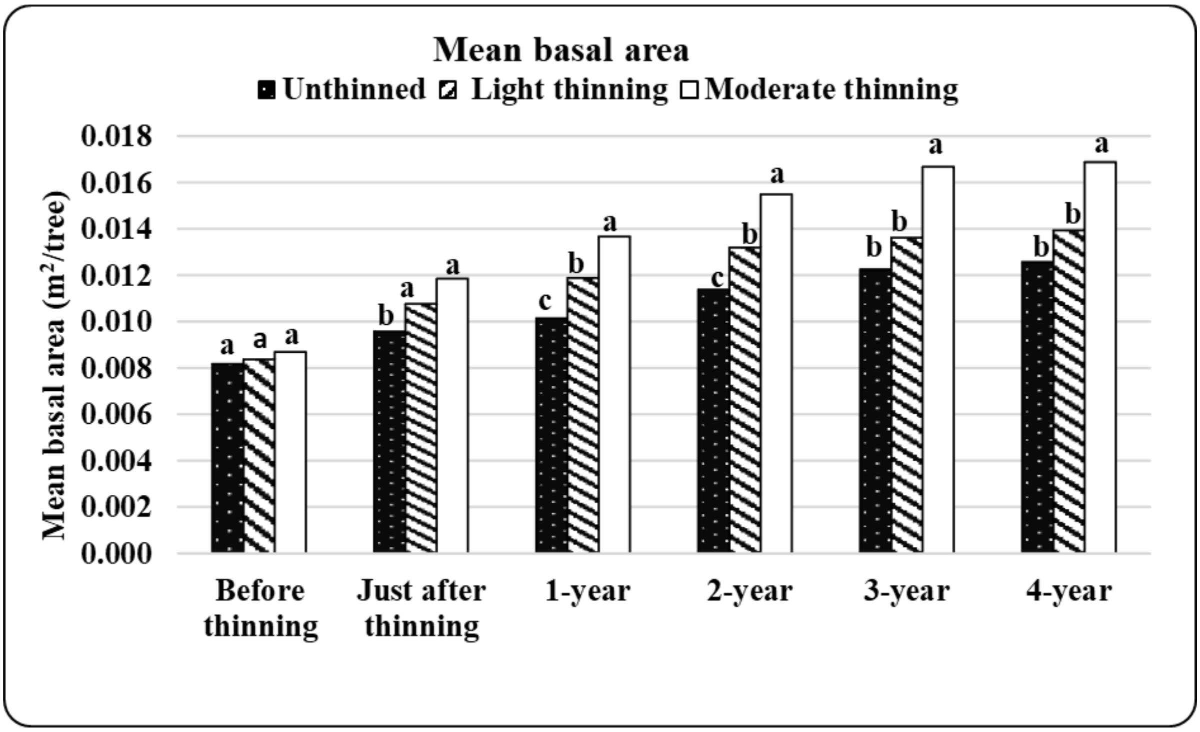


Figure 14-2. Mean basal area 4 years after thinning. Letters signify individual statistical differences among treatments in each measurement time, based on the ANOVA. The treatments marked with the different letters are significantly different ($p \leq 0.05$)

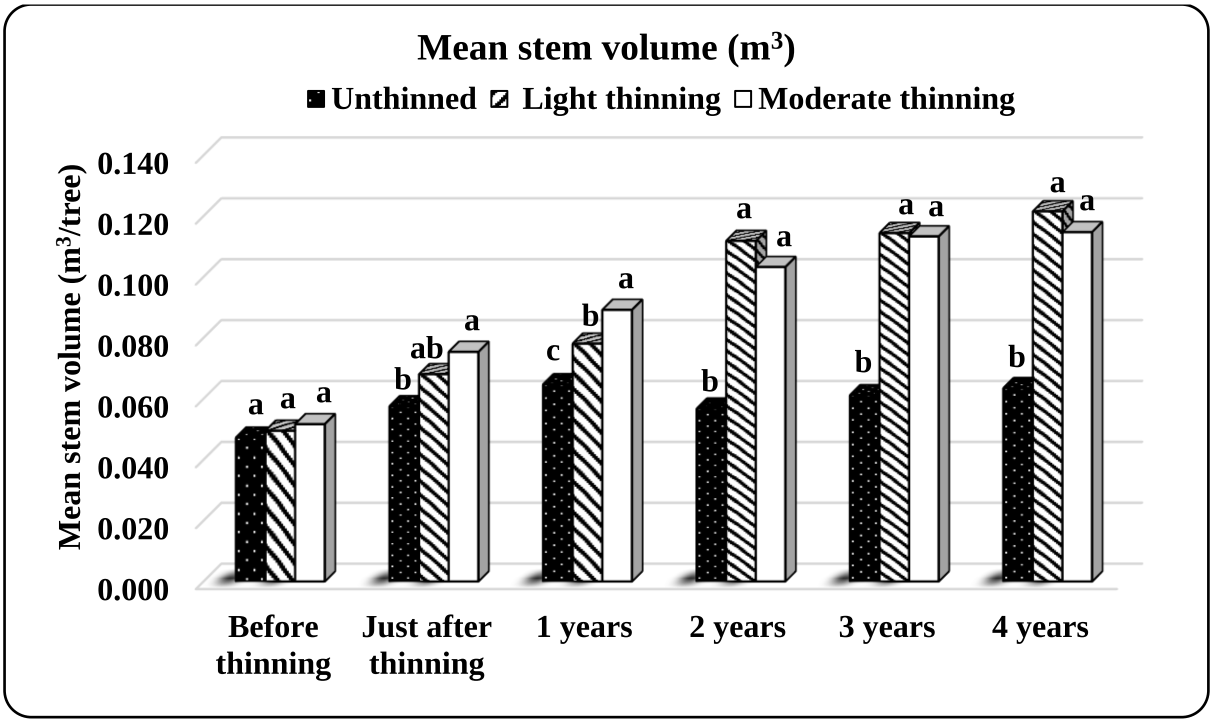


Figure 14-3. Mean stem volume 4-year after thinning. Letters signify individual statistical differences among treatments in each measurement time, based on the ANOVA. The treatments marked with the different letters are significantly different ($p \leq 0.05$)

Effects of thinning on tree growth

The mean annual DBH increments of all trees in moderate thinning plots were the largest, followed by those in unthinned plots and light thinning plots (Figure 14-4). The differences among thinning intensities were not statistically significant in all treatments. The mean diameter increment was also calculated for the dominant trees (defined as 100 largest tree by DBH per hectare).

The mean annual increment of the dominant trees was the largest in moderate thinning plots, followed by those in light thinning plots and unthinned plots. The test of mean annual increment of the dominants revealed the same result as for all the trees. This result indicated that thinning intensity had no clear effect on annual DBH increment of the dominant trees in the residual stands (Figure 14-4).

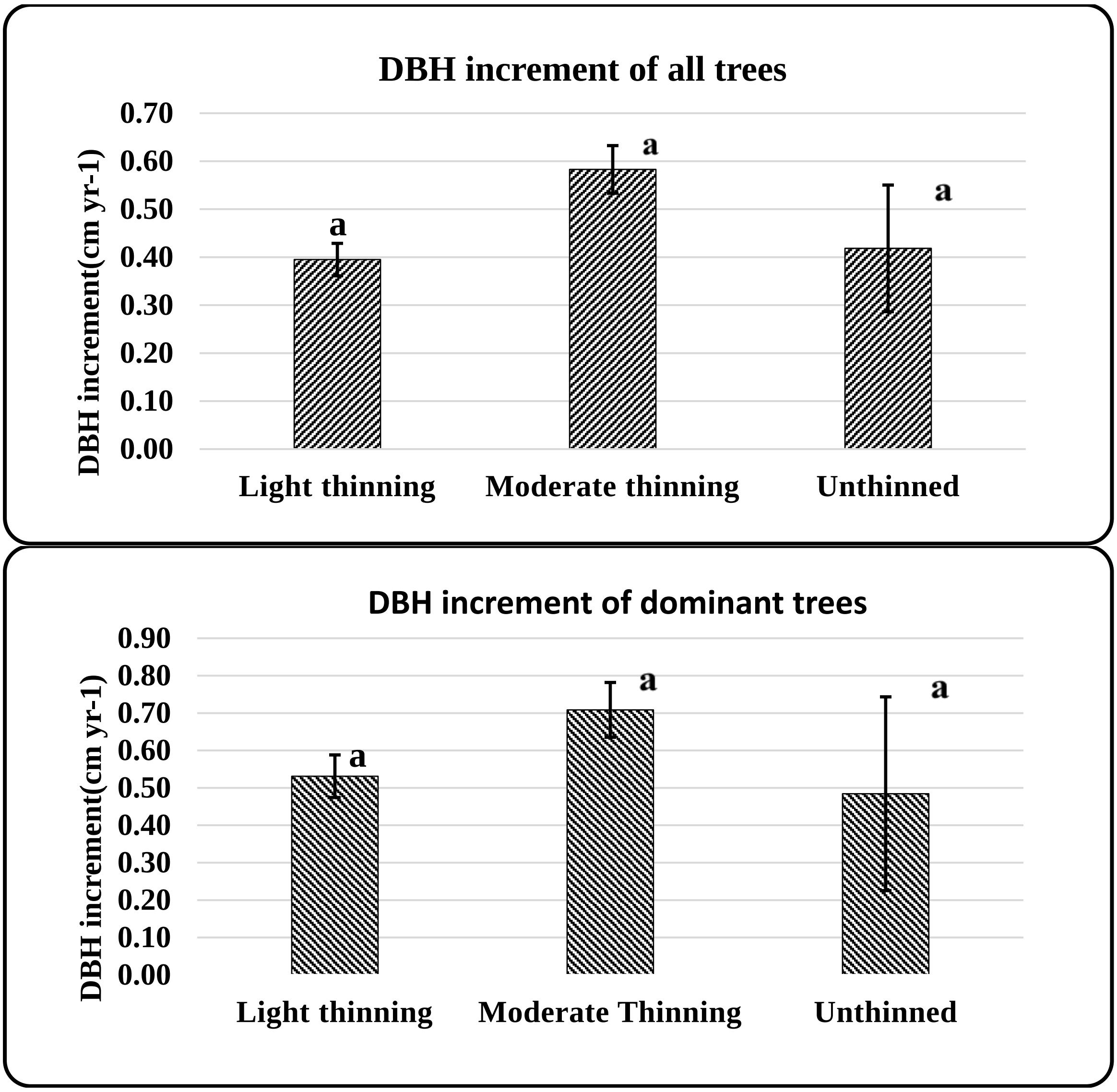
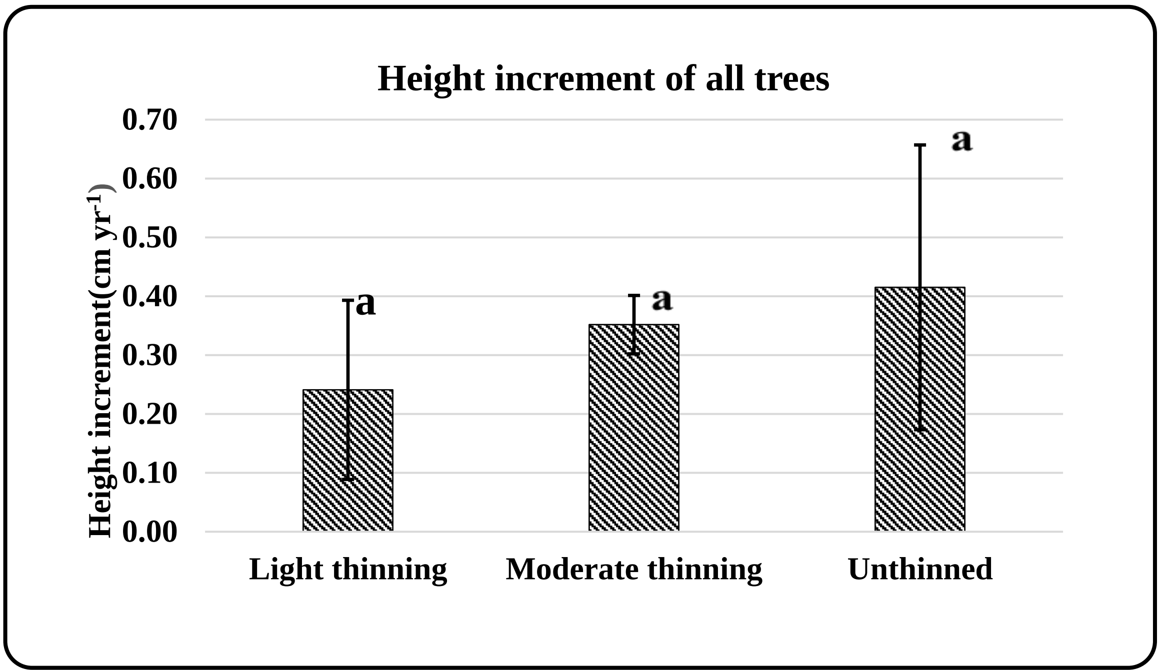


Figure 14-4. Mean annual DBH increment of all trees and dominant trees. Letters signify individual statistical differences among treatments in each measurement time, based on the ANOVA. The treatments marked with the different letters are significantly different ($p \leq 0.05$)

In the case of mean height of all trees and mean annual height increment of the dominant trees, the results were aligned with the results in mean annual DBH increment presented above. The mean annual height increment of all trees and the dominant trees were the largest in the control plots, followed by the moderate thinning plots and then the light thinning plots. The heavier thinning plots seemed to show a greater annual height increment of all trees and the dominant trees, but there was no significant difference (Figure 14-5).



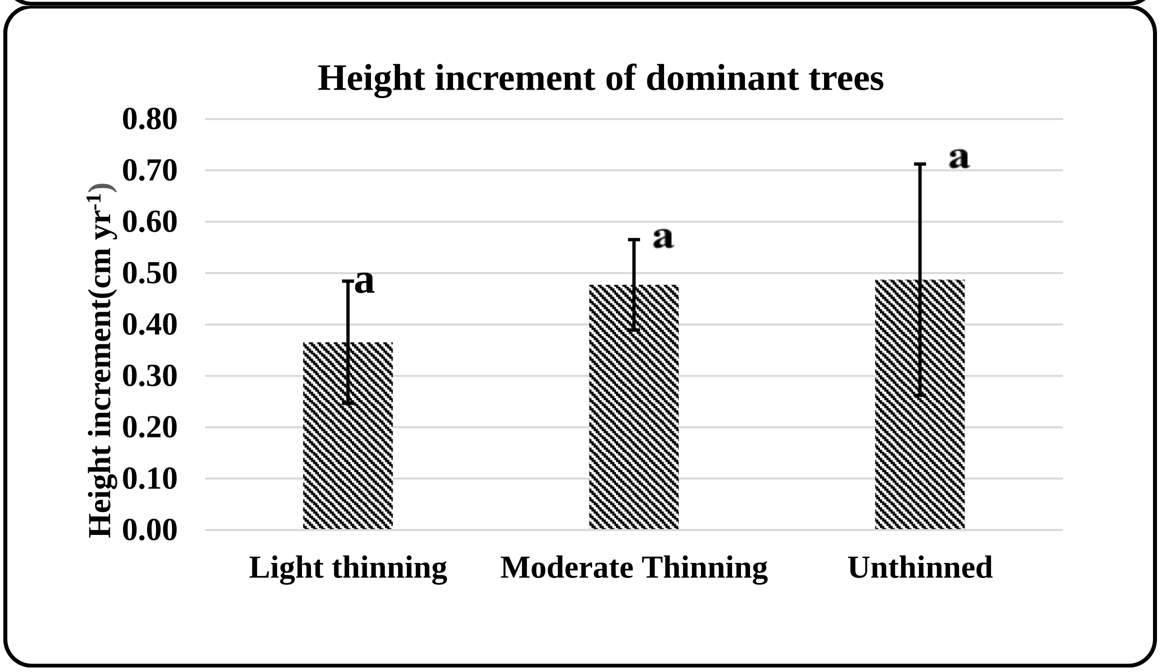


Figure 14-5. Mean annual height increment of all trees and dominant trees. Letters signify individual statistical differences among treatments in each measurement time, based on the ANOVA. The treatments marked with the different letters are significantly different ($p \leq 0.05$)

Effects of thinning on stand growth

The volume production of the residual stands calculated from the year of thinning was examined only in the fourth year after thinning, and the data are presented in Table 14-2. Total of volume production in each stand consisted of the volume of thinned trees, the volume of dead trees, and current volume production. The total volume production was the sum total of those three parts. The total volume of production in light thinning plots was the largest (112.16 m2 ha-1), followed by the moderate thinning plots and control plots. The number and volume of dead trees in control plots were much larger than those in both thinned plots, because of severe competition in control plots. The number and volume of dead trees was smallest in moderate thinning plots. This result may be caused the larger volume of production in moderate thinning plots than those in control plots. This result indicated that thinning prevented regular tree mortality.

Table 14-2. Stand volume production ($m^3 ha^{-1}$) in stands with different thinning intensities

Treatment	Volume of thinned trees	Volume of dead trees	Current volume production	Total volume production	No. of dead trees (tree)
Light	21.21	2.27	88.69	112.16	46
Moderate	36.77	0.94	55.71	93.42	19
Unthinned	0.00	7.85	63.47	71.32	227

The annual stand volume increment was larger in light thinning plots than those in moderate thinning plots, but there was no significant difference between the two thinning intensities. Compared with the

control plots, the annual stand volume increment in light thinning plots differed significantly. In contrast, annual stand volume increment in moderate thinning plots was not significantly different from the control plots (Figure 14-6).

The total stand volume production was largest in light thinning plots, followed by moderate thinning and then control plots. The differences between the thinning intensities were not statistically significant. The total stand volume production in moderate thinning plots was not significantly different from that in the control plots (Figure 14-7). These results were in accordance with the results of annual stand volume increment.

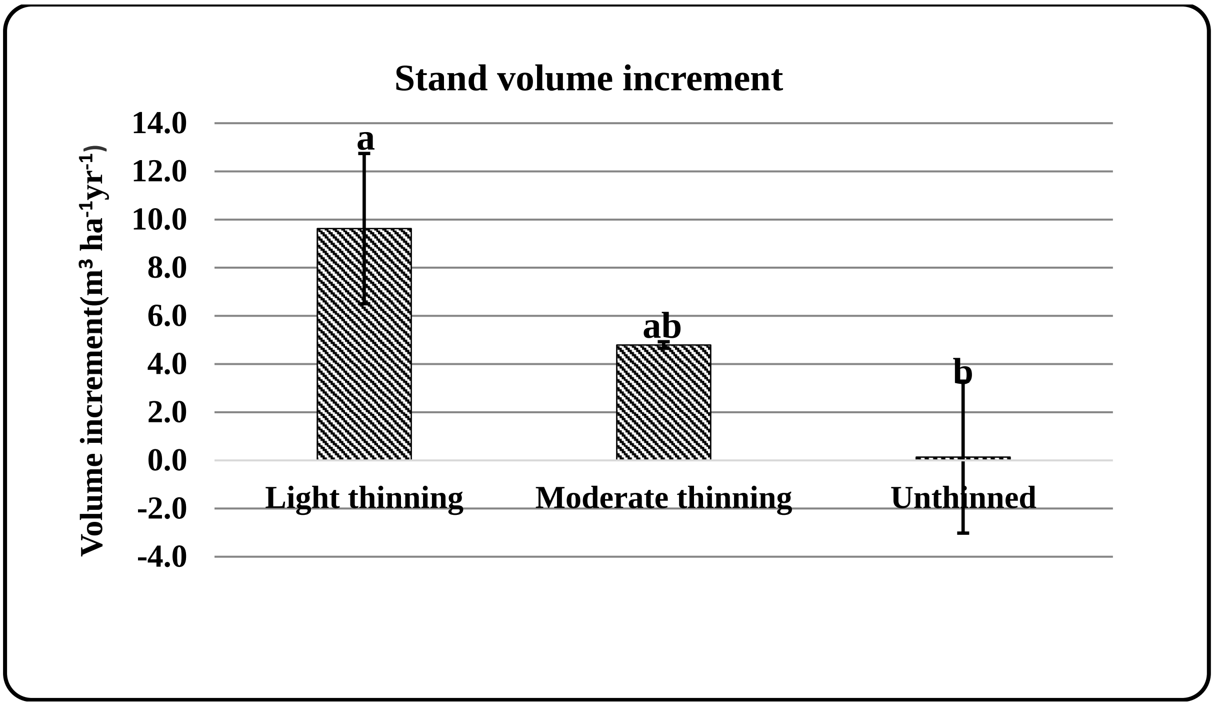


Figure 14-6. Mean stand volume increment. Letters signify individual statistical differences among treatments in each measurement time, based on the ANOVA. The treatments marked with the different letters are significantly different ($p \leq 0.05$)

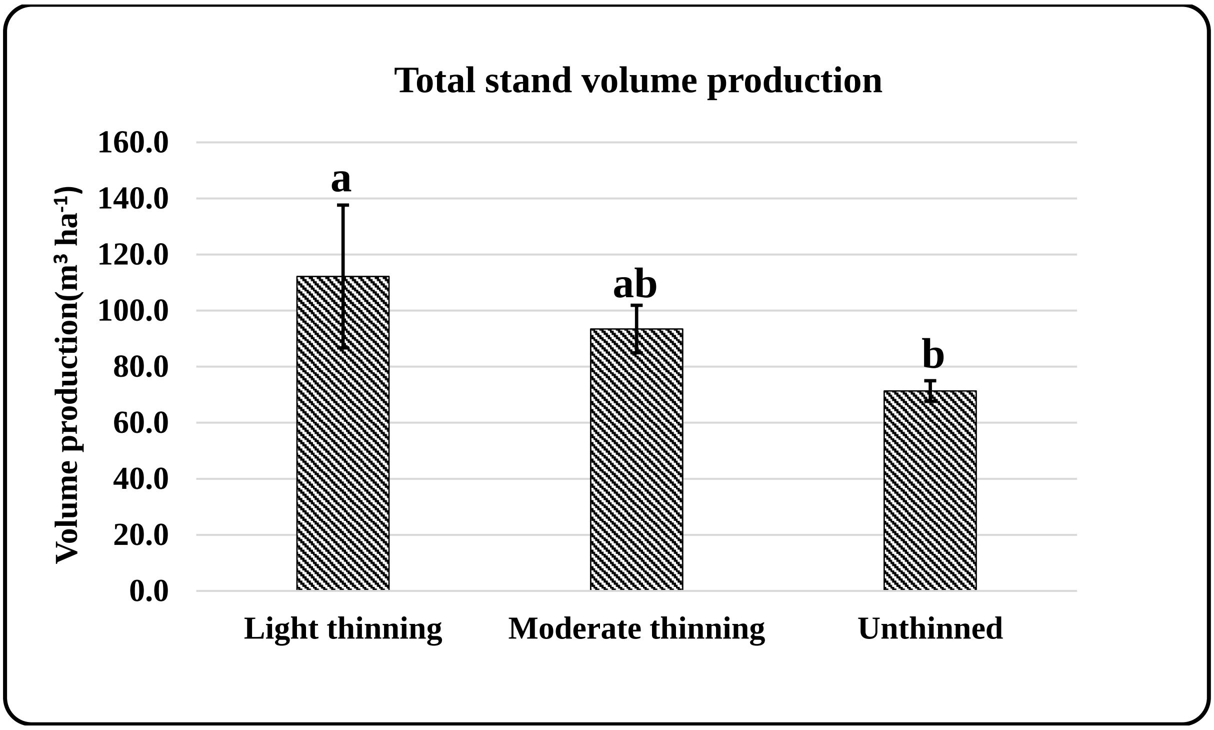


Figure 14-7. Total stand volume production. Letters signify individual statistical differences among treatments in each measurement time, based on the ANOVA. The treatments marked with the different letters are significantly different ($p \leq 0.05$)

Annual stand volume increments on the thinned and control plots during the whole measurement period were also examined in relation to the mean volume increment of control plots (Table 14-3). As expected, annual stand volume increment decreased with increasing thinning intensities. This result was in accordance with the result of current volume production. The moderate thinning intensity decreased the annual stand volume increment by 64% compared with the mean volume increment of the control plots prior to thinning. The light thinning intensity decreased the annual stand volume increment by 23%, whereas control plots showed a decrease in annual stand volume increment of almost 99%.

Table 14-3. Decrease in annual stand volume increment

Treatment	Annual stand volume increment ($m^3ha^{-1}yr^{-1}$)		
	Just after thinning	4 years after thinning	Decrease of annual volume increment (%)
Light thinning	12.29	9.62	-22.51
Moderate thinning	12.38	4.79	-64.30
Unthinned	11.80	0.13	-98.86

Effects of thinning on stem form

The effect of thinning on live-crown ratio was observed from the year thinning was performed 4th year after thinning. The live-crown ratio in thinned stand was larger than those in control plots from 1-year after thinning. Among thinned plots the live-crown ratio in moderate thinning plots was larger than those in light thinning plots by 2-year after thinning and clearly differed from 3-year after thinning (Figure 14-8).

On the other hand, slenderness ratio (slenderness coefficient) in the control plots was larger than those in thinned plots from 1-year after thinning. The slenderness ratio in moderate thinning plots clearly showed lower values than those in the light thinning plots and control plots, although the differences between the moderate thinning and control plots were not clear (Figure 14-8).

Absolute form factor clearly differed among treatments from 3-year after thinning. The form factor in light thinning plots yielded more cylindrical trees than those in moderate thinning plots and control plots. The form factor of all thinned plots was larger than those of control plots (Figure 14-9).

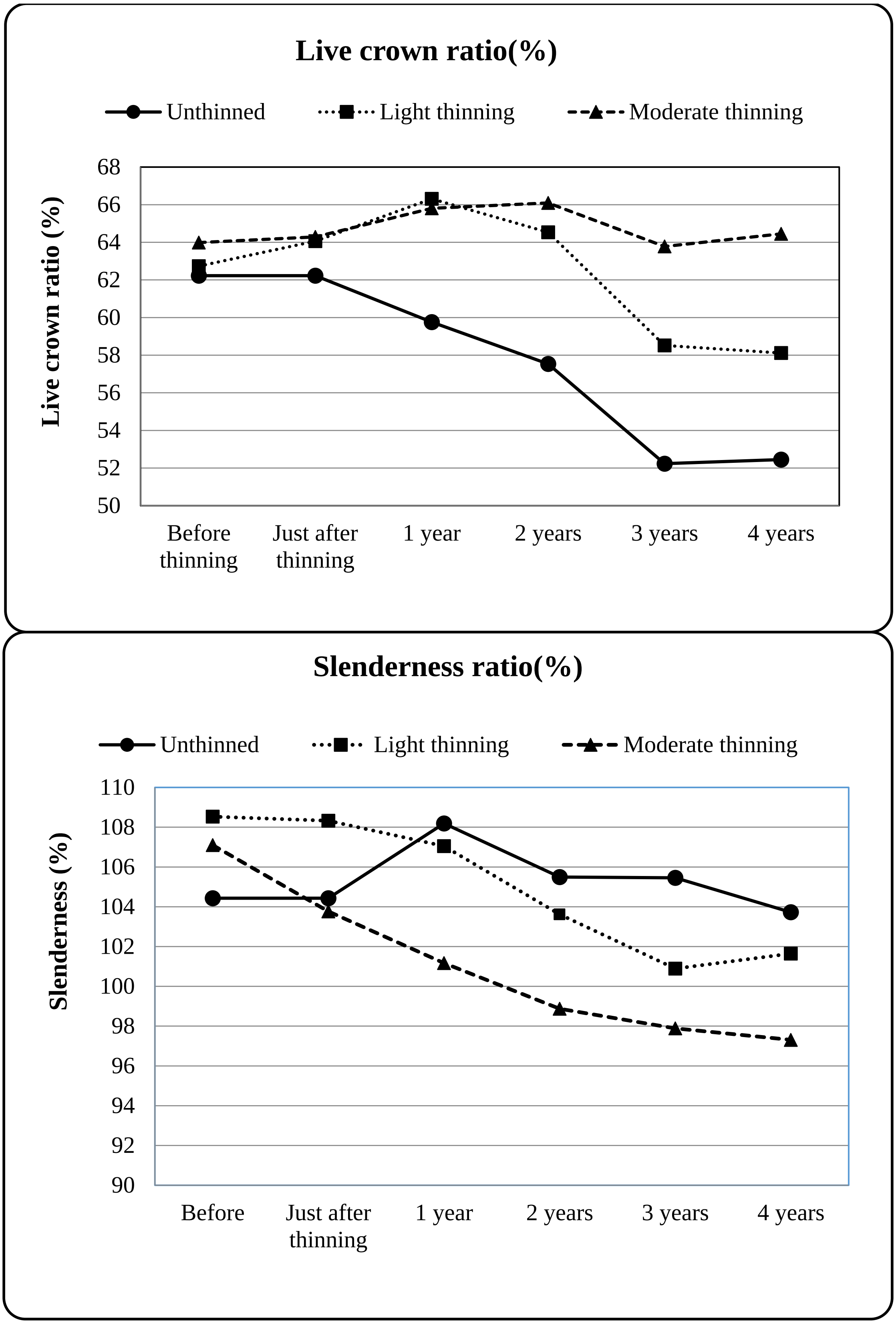


Figure 14-8. Live-crown ratio and slenderness before and after thinning

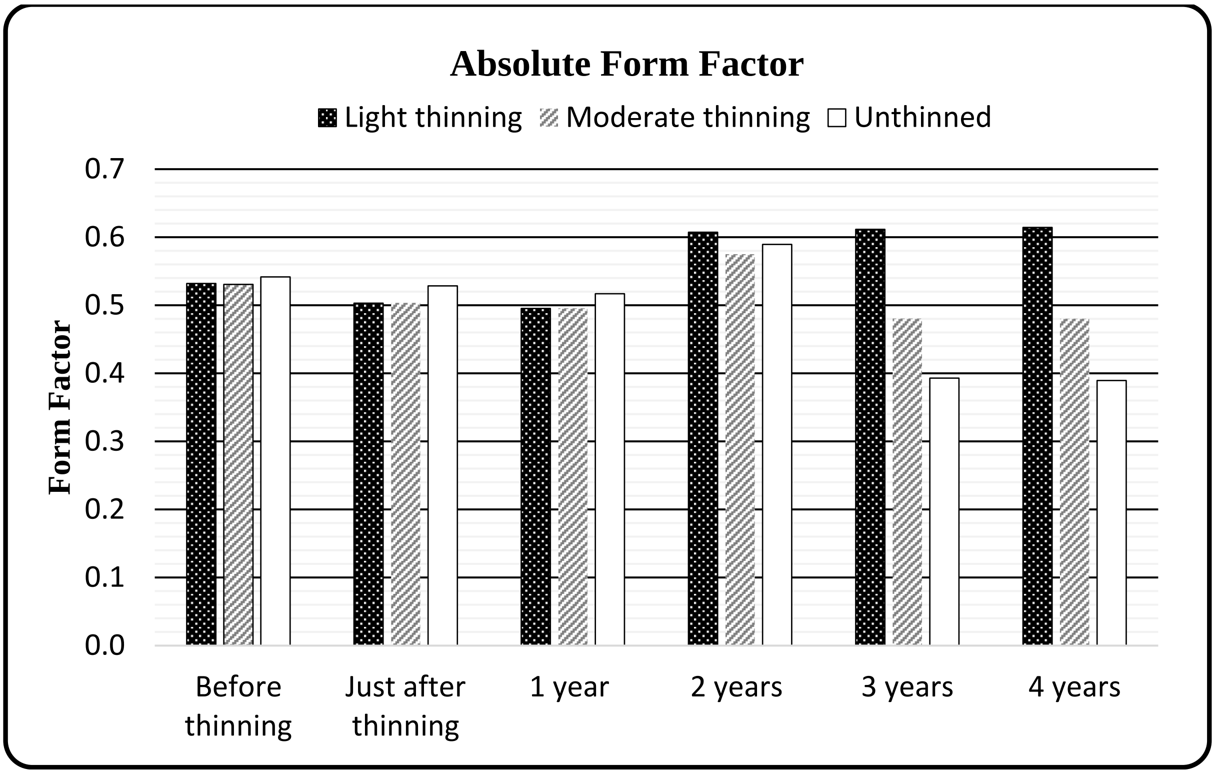


Figure 14-9. Absolute form factor before and after thinning

The effects of thinning on the three parameters contribute to the quality of stem form by 4-year after thinning, and the results are presented in Table 14-4.

The ANOVA results indicated that there were significant differences in live-crown ratio among treatments. The live-crown ratio in moderate thinning plots was larger than those in light thinning and control plots; however, there was no significant difference between moderate thinning plots and light thinning plots. Compared with the control plots, but the live-crown ratio in light thinning plots was not significantly different.

In contrast, the ANOVA results clearly indicated that there was no significant difference in slenderness ratio among the treatments. The slenderness ratio in moderate thinning plots was markedly different from the others because the value was less than 100%, whereas the corresponding values were higher than 100% in the other treatments.

As shown in Table 14-4, the absolute form factor in light thinning plots was the largest, followed by those in moderate thinning plots and control plots. The ANOVA results clearly showed that there were significant effects of thinning intensity on the absolute form factor.

Table 14-4. Parameters of tree attributes associated with quality of stem form: 4 years after thinning

Treatment	Live-crown ratio (%)			Slenderness ratio (%)			Absolute form factor		
Light thinning	58.11	(±3.96)	ab	101.65	(±3.56)	a	0.61	(±0.0200)	a
Moderate thinning	64.45	(±2.43)	a	97.31	(±1.91)	a	0.48	(±0.0005)	b
Unthinned	52.45	(±5.60)	b	103.73	(±1.71)	a	0.39	(±0.0050)	c

Treatments marked with the different letters are significantly different ($p \leq 0.05$); standard deviation in parentheses.

Discussion

The plantation responded to the first thinning, and the largest diameter increment occurred after moderate thinning (Figure 14-4). The results of this study were similar to the results of many other studies, especially in broad leaved stands (Hibbs et al., 1995; Rytter, 1995; Kerr, 1996; Clatterbuck, 2002; Meadows & Goelz, 2002). The increase in diameter growth in response to thinning was associated with an increase in photosynthetic rate and water and nitrogen use efficiency among thinned trees (Wang et al., 1995).

Height increment was not affected by thinning intensity in light or moderate thinning plots (Figure 14-5). Similar results were found in young stand of teak in Costa Rica after the first thinning was performed at 4 years (Kanninen et al., 2004). It is a well-known fact that the stand density has significant effects on diameter growth, but not on height growth, except for very high and very low stand densities. Our study results concurred with this finding.

The results clearly demonstrated that the remaining trees can rapidly occupy the growing space released by the thinned trees, especially in the light thinning plots. The DBH and height increment of all trees as well as that of the dominant trees clearly increased but there was no significant difference among thinned and control stands. The differences in diameter increment, basal area and volume in reaction to thinning can be explained by difference among tree species, site, stand age, tending practices, thinning type, and intensity (Hamilton, 1976). The results from our study support known information about the effects of thinning on stand production.

The total stand volume increment per unit area (per hectare) did not very much between the light thinning plots and moderate thinning plots, but there was significant difference from the control plots (Figure 14-7). The main reason was the dense control stands consumed more carbon for respiration than thinned stands; thus, net production will be reduced in dense stands (Savill et al., 1997). However, stand volume increment in the moderate thinning plots did not differ significantly from the control plots because a large number of trees were removed. The total stand volume production in the control plots was the smallest compared with the thinned plots (Table 14-2) because part of the total stand volume production was lost owing to severe competition in the stand. Therefore, thinning prevents natural mortality. The results in this study revealed that increasing thinning intensity resulted in only a small reduction in total stand volume production (from 112.16 m3ha-1 in light thinning plots to 93.42 m3ha-1 in moderate thinning plots) (Figure 14-7). However, the DBH increment of the remaining trees was clearly increased by thinning.

The results in this study revealed that thinning had a positive effect on stem form. Live-crown ratio in moderate thinning plots was largest and differed significantly from the control plots (Figure 14-8). It meant that moderate thinning expanded the crown size of the tree. Because we know that the crown contained the foliage which is the photosynthetic structure that provides carbohydrates for the growth and development of the whole tree (Larson, 1963; Leites & Robinson, 2004). The stem of a tree was strongly influence by its crown size and position (crown length, crown ratio and crown height). This result was confirmed in our study, whereby the mean stem volume of the individual tree in the control plots was the smallest compared with those in the thinned plots.

The slenderness ratios (or slenderness coefficients) of trees in the control plots were larger than those in the light thinning plots and moderate thinning plots, even though the difference among treatments was not statistically significant

(Table 14-4). The slenderness ratio has been widely used as an index of the stability of trees, especially the resistance of a tree to windthrow. The preferred slenderness ratio of a tree was lower than 100%. In this study, the slenderness ratio was lower than 100% (97.31%) only in the moderate thinning plots. It meant that the trees in moderate thinning stands may be at low risk for windthrow compared with the others. However, for teak Pérez & Kanninen (2005) reported from their study in a young stand of a teak plantation in Costa Rica, intensive thinning had a positive effect on the stem form, inducing the development of tree with desired proportion of DBH and total height. Trees suffering high competition in the control and light thinning treatments will hardly reach the total height/DBH ratio (slenderness ratio) of 1:1. However, there have been no similar studies in teak plantations for comparison. The absolute stem form factor was largest in the light thinning plots and differed significantly from the moderate thinning plots and the control plots. The control plots had the smallest value (Table 14-4). The larger stem form factor provided a more cylindrical volume of a tree. The result of this study confirmed this; the mean stem volume of individual trees at 4 years after thinning in the light thinning plots was largest compared with the others. Pérez & Kanninen (2005) reported in young teak plantations in Costa Rica that moderate early thinning yielded more cylindrical trees (average form factor of 0.46) than late thinning and control (unthinned) (average form factor 0.43 and 0.44, respectively). The result of our study in the moderate thinning plots provided a similar value of stem form factor found in early moderate thinning stands from their study.

Conclusion

The moderate thinning intensity (50% based on basal area) applied at the age of 6 years gave the largest values in terms of mean DBH, mean height, mean basal area, and mean stem volume of the individual trees, whereas the control showed the smallest values. The total height was not statistically different among treatments, although the mean height in the control treatment was smaller than that of the other treatments. The current stand basal area and stand volume at 4 years after thinning was the largest with light thinning intensity, whereas those with the moderate thinning intensity were the smallest.

The results from this study indicated that the mean DBH increment of all trees, as well as the mean DBH of the dominant trees, increased with increasing intensity, but there was no significant difference among thinned and control stands. The mean DBH increment of all trees in the control stands was similar those in the light thinning stands. On the other hand, the height increment of all trees and of the dominant trees was not affected by thinning intensity. The mean stand volume increment produced per hectare was largest in the light thinning stands and differed significantly from the control stands, however, it did not differ significantly from the moderate thinning stands. In case total stand volume production at 4 years after thinning, the results was in accordance with the results of the mean stand volume increment.

The light and moderate thinning intensities reduced the stand volume increment by 23% and 64%, respectively, in relation to the mean stand volume increment of the control stands, whereas the stand volume increment in the control stand decreased by almost 99%. However, part of the total stand volume production of the control stands was lost because of natural mortality.

Thinning intensity had effects on tree (stem) attributes that contributed to quality of stem form. Live-crown ratio increased with increasing thinning intensity. On the other hand, slenderness ratio decreased with increasing thinning intensity. The absolute form factor was clearly affected by thinning intensity. The form factor was significantly different among treatments, and control stands gave the smallest form factor; therefore, thinning practice tended to have positive effect on stem form even in a young stand of teak.

References

Clatterbuck, W. K. (2002). Growth of a 30-year cherrybark oak plantation 6 years after thinning. In: *Proceedings of the Eleventh Biennial Southern Silvicultural Research Conference* (ed. K. W. Outcalt), pp. 189-192. USDA Forest Service. Gen. Tech.Rep, SRS-48, Asheville, North Carolina, USA.

Hamilton, G. J. (1976). Effects of line thinning on increment. *Forestry Commission Bulletin, 55,* 37-45.

Hamilton, G. J. (1981). The effects of high intensity thinning on yield. *Journal Forest, 54*, 1-15.

Hasenauer, H., Burkhart, H. E. & Amateis, R. L. (1997). Basal area Development in thinned and unthinned loblolly pine plantation. *Canadian Journal of Forest Research, 27*, 265-271.

Hibbs, D. E., Emmingham, W. H. & Bondi, M. C. (1995). Response of red alder to thinning. *Western J. Applied Forestry, 10*, 17-23.

Horne, R., Robinson, G. & Gwalter, J. (1986). Response increment: a method to analyze thinning response in even-aged forest. *Forest Science, 32*(1), 243-253.

Kanninen, M., Pérez, D., Montero, M. & Viquez, E. (2004). Intensity and timing of the first thinning of Tectona grandis plantations in Costa Rica: results of a thinning trial. *Forest Ecology and Management 203*(1-3), 89-99.

Kerr, G. (1996). The effect of heavy on 'free growth' thinning on Oak (Quercus petraea and Q.robur). *Forestry, 69,* 303-317.

Larson, P. R. (1963). Stem form development of forest trees. *Forest Science Monograph, 5,* 1-42.

Leites, L. P. & Robinson, A. P. (2004). Improving taper equations of loblolly pine with crown dimensions in mixed-effects modelling framework. *Forest Science, 50*(2), 204-212.

Meadow, J. S. & Goelz, J. C. G. (2002). Fourth years effects of thinning on growth and epicormics branching in a red oak-sweetgum stand on a minor stream bottom site in west-central Alabama. In: *Proceedings of the Eleventh Biennial Southern Silvicultural Research Conference* (ed K. W. Outcalt), pp 201-208. USDA Forest Service, Gen Tech SRS-48, Asheville, North Carolina, USA.

Pérez, D. & Kanninen, M. (2005). Effect of thinning on stem form and wood characteristics of teak (*Tectona grandis*) in a humid tropical site in Costa Rica. *Silva Fennica, 39*(2), 217-225.

Rytter, L. (1995). Effects of thinning on the obtainable biomass, stand density, and tree diameters of intensity grown grey alder plantations. *Forest Ecology and Management, 73*, 135-143.

Savill, P., Evans, J., Auclair, D. & Falck, J. (1997). *Plantation Silviculture in Europe*. Oxford University Press, New York, USA.

Vacharangkura, T., Mungklarat, J., Kheannak, P., Wattanasuksakul, S., Nongnueang, S. & Krongkitsiri, V. (2001). *Growth and yield prediction of economic forest plantation*. Final Report Silvicultural Research Group. Forest Research and Development Bureau Royal Forest Department, Bangkok, Thailand. 61 p. (in Thai).

Wang, J. R., Simard, S. W. & Kimmins, J. P. (1995). Physiological responses of paper birch to thinning in British Columbia. *Forest Ecology and Management, 73*, 177-184.

Zeide, B. (2001). Thinning and growth: a full turnaround. *Journal Forest, 99,* 20-25.