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

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Federal Ministry of Food and Agriculture

BMEL-ITTO Project:
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Production of Good-Quality Planting Material

Chumnun Piananurak

Technical Report

Technical Report

PRODUCTION OF GOOD-QUALITY PLANTING MATERIAL

By

Chumnun Piananurak

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)

CONTENTS

BACKGROUND

The ITTO Teak project in Mekong, "**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 Timber Council Meeting in Lima, Peru in November 2017 and the Global Landscapes Forum in Bonn, Germany, in December 2017. At ITTC 53, the Council approved ITTO's 2018-19 Biennial Work Program (BWP) with the ITTO Budget (Government of Germany) of USD 1,236,250. The duration of the project is 3 years from March 1, 2019 to September 30, 2022.

The objective of the Project is to demonstrate legal and sustainable teak supply chains with the engagement of local communities, smallholders and government actors in the Greater Mekong sub-region (GMS). The project expects 3 outputs: 1) The conservation of teak genetic resources, sustainable management and use of natural teak forests and market accesses of teak from legal sources have been shown, 2) Community-based and smallholders teak forest management and agro-forestry systems have been strengthened with improved legal and sustainable supply chains, and 3) Regional and international collaboration, information sharing and knowledge management, networking, policy development and outreach on the sustainable management of teak forests, including sustainable use of teak genetic resources have been strengthened.

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 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 in the GMS include 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 from 1990 resulting in significant impacts on natural and forest resources.

The Project Activity is aimed at assisting governments, local communities and smallholders to enhance natural teak forest management, production and marketing to facilitate the establishment of legal and sustainable wood supply chains while improving national economy and local communities' livelihood in the Greater Mekong Sub-region. The Activity provides an opportunity for the recipient countries to build-up sustainable forest management capacities and to further pursue their strategic objectives and policies on the sustainable development of teak forest resources, which are of particular livelihood improvement and ecological significance in all countries of the Greater Mekong Sub-region.

In order to implement the ITTO Teak Project in Mekong effective, the **Consultant#2: Production of good-quality planting material** was recruited to develop quality standards for teak planting material on a regional level.

THE PRINCIPAL TASKS AND RESPONSIBILITIES

The principal tasks of the **Consultant #2: Production of good-quality planting material"** is to take overall responsibility to engage in conservation of teak genetic variation through improved management of existing seed production areas, seed orchards, and provenance/progeny trials (Lao PDR, Myanmar, Thailand) (Activity 1.3).

The specific functions and responsibilities include:

- Develop quality standards for teak planting material on a regional level according to existing schemes for the control of reproductive material
- Work with relevant agencies to identify existing sites to conserve teak genetic variation
- Support the production of good-quality planting material and disseminate products to the participating countries upon request
- Develop and implement a capacity building program for teak improvement and the mass propagation of quality forest reproductive material including public and private nurseries.
- Carry out all activities in close cooperation with scientists and researchers from participating countries
- Present activity outcomes, results and findings to the Project Technical Committee (PTC)
- Compile all results and findings, incl. recommendations for follow-up actions, in a final report in the English language and Teak Networking System to be submitted to the Regional Activity Manager
- Assist in other activities assigned by the Regional Activity Manager
- Available to provide recommendations and advises to National Coordinators, PTC members (if any).
- Undertake international travel, as and when required

EXPECTED DELIVERABLES

The consultant should submit the following outputs to the Regional Activity Manager:

- Submission of three guidelines briefs on production of good-quality planting material (around 4 pages - beginning, middle and end of the consultancy work).
- Report of assigned training/workshop
- A brief travel report (if any)
- Technical report on quality standards for teak planting material on a regional level suitable for the GMS countries

DELIVERED OUTPUTS

Summary of delivered outputs of consultant#2 during the reporting time (April 2019 – June 2021) include:

Year	Tasks
2019	1. Attended the 1st Project Steering Committee Meeting and Project Technical Committee on 23 April 2019 @Chaophaya Park Hotel,Bangkok Thailand, and joined the field trip to Lampang province on the 25 April and presented the Northern Seed Center and Ngao Silvicultural Research Station activities to participants as reported in Teak Mekong Newsletter June 2019 - Volume 1(1) 2. Prepared and conducted **"Joint Training Workshop on Teak Propagation Technique and Silvicultural Practice"**, 5-9 August 2019 at Elephant Training Center, Lampang Province as reported in Teak Mekong Newsletter August 2019 - Volume 1(2) 3. Attended Regional Workshop on Sustaining Teak Forests in Mekong Basin, 24-27 September 2019, Yangon, Myanmar. Presented the presentation entitled **"Teak Plus Tree Selection and Its Propagation Techniques used 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 an article on **"Propagation of Teak for Clonal testing: Part I (Budding or Bud-grafting)"** in ITTO - Teak Mekong Newsletter June 2020 - Volume 2(3) 3. Prepared "**Training workshop on "Plus Tree Selection, Seed Orchard Establishment and Agro-Forestry",** in ITTO - Teak Mekong Newsletter April 2021 - Volume 3(2). The workshop was postponed due to the COVID -19.

4. Provided recommendations and advises for smallholders and demonstration plots at Maegar Silvicultural Research Station on teak propagation technique and clonal test plan.

5. Published Policy Brief on **"Production of Good Quality Teak Planting Material"** in ITTO - Teak Mekong Newsletter August 2020 - Volume 2(4)

6. Submitted abstract and poster entitled **"Effect of serial harvesting of shoots on rooting ability of teak clones"**, to the XV World Forestry **Congress** (WFC 2021)

2021 1. Attended the 2nd Monthly Webinar Meeting and gave presentation entitled "**Progress on teak genetic improvement in Thailand"**, on 25 February 2021 in ITTO - Teak Mekong Newsletter April 2021 Volume 3(2)

2. Published an article on **"Propagation of Teak for Clonal testing: Part II (Cutting)"** in ITTO - Teak Mekong Newsletter August 2021 - Volume 3(4)

3. Published an article on **"Propagation of Teak for Clonal testing: Part III (Planting)"** in ITTO - Teak Mekong Newsletter October 2021 - Volume 3(5)

4. Prepared an article on **"Improving Teak Resources in Mekhong"** Expected to be published in TFU Newsletter released in mid-December 2021 -

5. Preparing two book chapters related to teak improvement and propagation for book entitled "**Sustainable Management of Teak (*Tectona grandis*) in the Mekong Region**". Titled "**Teak Plus Tree Selection and Its Propagation Techniques used in Thailand" and "Progress in Teak Improvement Program in Thailand**"

6. Prepared and submitted first draft of final technical report on quality standards for teak planting material on a regional level suitable for the GMS countries titled "**Production of Good-Quality Planting Material of Teak**"

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#5)

The delivered outputs can be categorized to 3 groups:

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

1) Training Workshops

1.1) Joint Training Workshop on "Teak Propagation Technique and Silvicultural Practice"

A joint training workshop on "Teak Propagation Technique and Silvicultural Practice" was held during 5-9 August 2019 at Elephant Training Center, Lampang Province. The objectives of joint workshop were 1) To introduce participants to basic genetic improvement of teak and selection of materials for propagation. 2) To introduce participants basic principle of plant propagation.3) To train participants on various techniques to propagate teak by using seed and vegetative materials. Joint training workshop approaches included lecture, brainstorm, exercise, discussion, and field demonstration. Forty-five participants attended the workshop. Majority were private and smallholder teak plantations (20 persons), followed by field staffs of Forest Industry Organization (15 persons), relevant staffs from RFD (5 persons) and officials or smallholders from the remaining 4 participating countries (3 persons each).

Lectures included overview selection of high-quality genetic materials for propagation, seed propagation, seedling/stump production of teak, vegetative propagation techniques of teak were provided in the morning, followed by field practice on "vegetative propagation techniques-budding and rooted cutting" in the afternoon. Outputs of the training were fruitful. Trainees were able to identified high improved genetic materials to be used for their own conditions. Participants were able to choose the right technique to propagate teak from different stages of materials and situation. Participants were able to propagate teak using various techniques. Some participants became instructors and conducted training and workshops in their own respective countries.

Photo 1. Joint Training Workshop on Teak Propagation Technique and Silvicultural Practice", 5-9 August 2019 at Elephant Training Center, Lampang Province, Thailand.

1.2) Joint Training Workshop on "Plus Tree Selection, Seed Orchard Establishment and Agro-Forestry"

A Joint Training workshop on "Plus Tree Selection, Seed Orchard Establishment and Agro-Forestry", was prepared as appear in ITTO - Teak Mekong Newsletter April 2021 - Volume 3(2). The workshop was postponed due to the COVID -19 until 21-25 February 2022 the workshop was finally held at PM Place hotel, Muang, Phayao province. The objectives of joint workshop were 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 selection of teak. 4) to introduce participants to principle of teak seed orchard establishment and management. 5) to introduce participants to principle of agroforestry practice. 6) to train participants the technique agroforestry plantation management. Joint training workshop approaches included lecture, brainstorm, exercise, discussion, and field demonstration. Thirty participants attended the workshop. Majority were private and smallholder teak plantations (10 persons), followed by field staffs of Forest Industry Organization (10 persons), relevant staffs from RFD (10 persons).

Lecture on progress of teak improvement in Thailand participants were briefed on the up to date of teak genetic improvement in Thailand. Procedures of teak plus tree selection were presented to participants by power point slides and posters. After the presentation participants were divided into 3 groups. Each group was assigned to select a plant for their improvement project and set up criteria and standard for it plus tree. Each group presented their project and open discussion were done during presentation. After the session, all participants learned how to select a plus tree. On Seed orchard establishment, after a brief presentation on seed orchard condition, each group was assigned to draft a work plan to establish clonal seed orchard or seedling seed orchard follow the instruction given in a text book. The participants were brainstorming and sharing experience to finish their assignment and open discussions was done during presentation. Ms. SompornKamshompoo, invited speaker, presented about activities run at Mae gar seed orchard.

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 2. Joint Training Workshop on “Plus Tree Selection, Seed Orchard Establishment and Agro-Forestry”, 21-25 February 2022 at PM Place hotel, Muang, Phayao province, Thailand.

2) Presentations

2.1) Presentation on "the Northern Seed Center and Ngao Silvicultural Research Station activities" Presentation was given to participants who joined the field trip to Lampang province after the 1st Project Steering Committee Meeting and Project Technical Committee on 25 April 2019. The key messages of presentation were the main responsibility of the center and the station where was the well-known "Teak Improvement Center" in the former time. The center conducts experiment on seed production, procurement, management and provide good quality seeds to selected stations. Presentations at Ngao Silvicultural Research Station were about teak improvement program in Thailand and progress in various breeding techniques, criteria for selection of teak plus tree, and propagation techniques of teak including tissue culture.

Photo 3. Post field trip to Lampang province after the Project Steering Committee Meeting and Project Technical Committee on 25 April 2019

2.2) Teak Plus Tree Selection and Its Propagation Techniques used in Thailand

Presentation entitled "Teak Plus Tree Selection and Its Propagation Techniques used in Thailand" was given in the regional workshop on Sustaining Teak Forests in Mekong Basin, during 24-27 September 2019, Yangon, Myanmar. This presentation was in session 3: Sustainable management of teak forest – R&D in silviculture and best practices. The summary of presentation is presented as following.

Characteristics to selection of Plus trees are dependent on the end use of the wood produced. Since teak fetches highest prices when usable as veneer, marine decking, furniture, etc., its stem form and wood texture are the most important traits for selection. Once plus tree is selected it could be propagated by both seed and vegetative part. Propagation by seeds is the easiest technique used by small farmers. Teak can be vegetatively propagated by budding, rooted cutting and tissue culture. Budding technique by Open-two-flap was used for a long time until Chip-patch technique was developed which lends itself to very fast paced application. Budding is most successful when propagating mature material because budded shoots are rejuvenated and become suitable for carrying out rooted cutting or tissue culture. It is not advisable to use budded seedlings to directly establish clone bank, clonal test, or CSO due to the concerns of incompatibility and possible contamination of root stock plants if budded shoots have not been monitored properly. Rooted cutting is the cheapest, most successful, and easiest method to propagate juvenile material of teak but is less successful when mature materials are used. In the case of mass production of elite plants, it is preferable to use tissue culture to produce juvenile stock plants for rooted cutting.

Photo 4. Presentation in Regional Workshop on Sustaining Teak Forests in Mekong Basin during 24-27 September 2019, Yangon, Myanmar.

2.3) Effect of serial harvesting of shoots on rooting ability of teak clones (Abstract and poster was submitted for World Forestry Congress)

Abstract of poster presentation entitled "Effect of serial harvesting of shoots on rooting ability of teak clones" has been accepted for preparing a poster in poster session at the XV World Forestry Congress (WFC 2021), sub-theme 3: The green pathway to growth and sustainability. Due to the continued and unprecedented challenges of the global health pandemic, it is increasingly clear that it will not be possible to hold a safe, inclusive World Forestry Congress on the originally scheduled dates of 24 to 28 May 2021 in Seoul. The Congress will therefore be postponed to 2 to 6 May 2022.

The abstract of the article titled "Effect of serial harvesting of shoots on rooting ability of teak clones" presented as following. Rejuvenation of shoots through budding and serial harvesting was carried out to produce shoots for rooted cutting of 106teak clones.3-month-old budded seedlings were topped and leaf pruned to stimulate secondary shoots that used for rooted cutting. 1-month old secondary shoots were harvested and rooted cutting in non-mist propagators. Number of shoots per stock and rooting ability of each clone were recorded for6 consequences shoot harvesting at 2 weeks interval.1 month after propagating showed that rooting ability were high significantly (Pr (>F) = 0.489) difference among clones.35 clones had high rooting ability averaged more than 60percent, 56 clones had 40-60 percent, while 15 clones had less than 40 percent. Number of shoots per stock and rooting ability were high significantly affected by order of consequence shoot harvesting. Average number of shoots per stock were 0.85, 0.87, 0.74, 0.88, 0.70and0.60 shoots (not every stock plant produce shoot in every harvesting round) while rooting ability were 54.01, 44.37, 19.68, 63.87, 81.90and 73.63 percent for 1st to 6th shoot harvesting respectively. Number of shoots per stock increased from 1st until 4th cut and then decreased when 5th and 6th cut. Later harvesting trended to increase rooting ability.

2.4) Progress on teak genetic improvement in Thailand.

Paper titled **"Progress on teak genetic improvement in Thailand**" was presented at the second virtual monthly webinar meeting which was held on 25 February 2021. The key messages of presentation summarized as follow.

Teak genetic improvement in Thailand was started in 1965. The improvement program was set up and the progress of its current scenario was presented. 636 plus trees were selected following the standard criteria. A total of 511 plus trees were planted in a total of 5 clone banks across the country. When plus trees were selected, only phenotype could evaluate. Genotypic property of the clone could be evaluated through clonal test. There were 3 clonal test sets conducted in Thailand, the first one using the budding techniques for propagation for 100 clones, and tested only one site. Later, when rooted cutting of teak are well practiced, there was a new set of testing using a total of 400 clones, divided into 4 years, 100 numbers per year and planted in 4 sites. The last set of 100 numbers was taken up as part of the ITTO-Teak Mekhong project, propagated and planted in 2021. There was a total of 100 plus trees used in the Clonal Seed Orchards. Progeny test using 2 types- full-sib progeny and half-sib progeny tests were employed. These tests are considered as a genetic improvement process which results in better genetic quality trees. The good quality off springs could be propagated for high genetic value plantations or for a higher improvement program. Since there are improved genetic materials available for public, it is recommended that the ITTO Teak in Mekong project supports farmers to produce high quality teak.

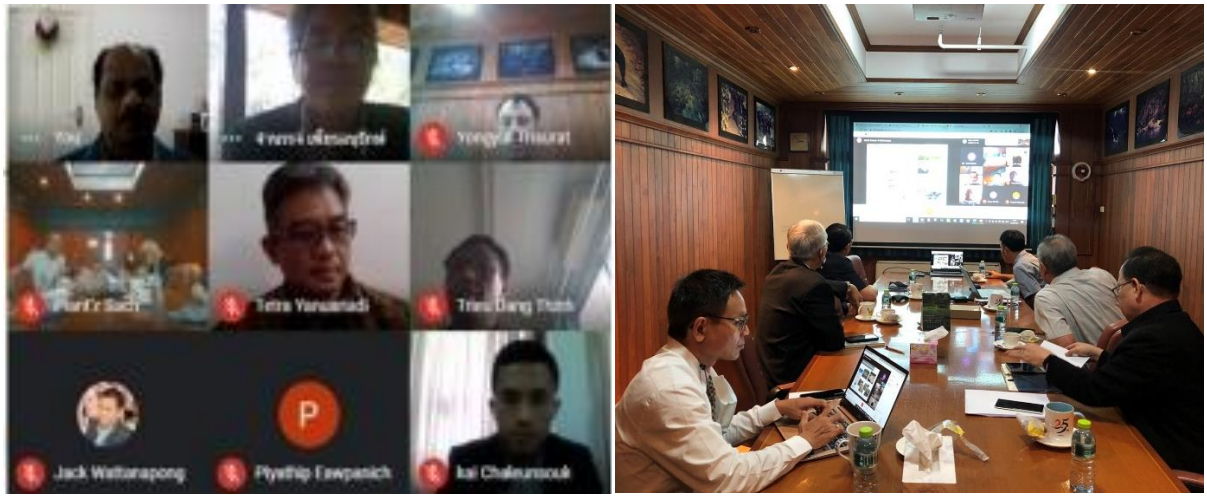

Photo 5. The second Virtual Monthly Webinar Meeting on 25 February 2021.

3) Publications

3.1) Policy Brief "Production of good-quality planting material"

This policy brief published on Teak Mekong Newsletter June 2020 - Volume 2(3). The contents of this policy brief are overview of teak improvement program and process. The progress status of teak improvement in each counterpart country was summarized. Since the progress statuses of teak improvement were varied among counterpart countries, recommendations were made separately to individual country.


ITTO-TEAK IN MEKONG

Bi-monthly online

Teak Mekong Newsletter

August 2020 - Volume 2(4)

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TEAK Mekong Newsletter support and facilitates teak networking in the Mekong sub-region through ITTO member countries and partners, and support sharing lessons of the project results through short news release, occasional papers, project related teak-based research and development information. The bi-monthly newsletter is released online through TEAKNET webpage www.teaknet.org and co-hosted by Kasetsart University, Thailand.

Policy Brief

Making teak an attractive agroforestry tree for smallholders in the Mekong Sub-region

Dr Promode Kant[1]

Teak, easily the most favored timber species across the world that has a ready market everywhere, is native to South and South-East Asian countries and comes up very well both within the forest ecosystems as well as on cultivated lands of the Mekong sub-region. The farmers and smallholders of this region are aware of the potential of this resource and are usually keen to enhance their incomes by growing it on medium rotation as an agriculture intercrop and sometimes as exclusive teak plantations on marginal lands of low agriculture productivity.

There is no single official definition of smallholding because what could be considered small in one country may be seen quite large in another. The Lomé Statement[2] for Smallholder Forest Landscape Restoration (FLR) in West Africa of November 2019 notes that smallholders "are most often classified according to their size, which can vary from less than one hectare up to 10 hectares and more. Legally, smallholders can be individuals, family or clan

In the heavily populated Mekong sub-region the per capita land availability is very low with Vietnam at 0.12 ha being at the bottom, followed by Myanmar (0.24 ha) while the extents for the remaining three countries of Cambodia, Laos and Thailand are almost similar at 0.36, 0.33 and 0.34 ha respectively. Land holding in the region is typically small with as many as 85% in Vietnam, 38% in Laos, 34% in Myanmar, and 23% in Thailand being less than 1 ha[3]. The data for Cambodia could not be accessed. Given this nature of landholding, it appears judicious to take 1 ha and less of landownership in a family as a good measure of smallholding in the crowded Mekong sub-region.

Until about three decades back the owners of these smallholdings were almost exclusively subsistence farmers but the situation has gradually changed since 1980s with rapid expansion of the south-east Asian economy giving attractive employment opportunities to the

Fig 2 Small farmers produce teak seedlings for sale using conventional technique

Fig 3 Some farmers can produce rooted teak cuttings seedlings of high genetic materials after the training

Photo 6. Policy brief on entitled **"Production of good-quality planting material**"

3.2) Propagation of Teak for Clonal testing: Part I (Budding or Bud-grafting)"

An article entitled "Propagation of Teak for Clonal testing: Part I (Budding or Bud-grafting)" were published as co-author with Somporn Khumchompoo and Apachara Meaungkom was published in ITTO - Teak Mekong Newsletter June 2020 - Volume 2(3) in ITTO - Teak Mekong Newsletter June 2020 - Volume 2(3). The content of the article is as following.

Clonal test is a field planting of many vegetatively propagated plants to estimate the relative performance of different genotypes. Clonal test of 400 clones out of 500+ plus trees selected in the Teak Improvement Program in Thailand has been conducted a decade ago. Clonal test of the rest plus trees is an activity proposed by a demonstration site at Maegar Silvicultural Research station, Phayao province, Thailand to the ITTO Teak Project in Mekong. Vegetative propagation used for teak clonal test is rooted cutting which requires juvenile materials to be success. One technique to rejuvenate material of teak is budding or budding grafting. The progress of teak budding conducted at Maegar Silvicultural Research station are reported.

Photo 7. Teak budding techniques to rejuvenile mature material for rooted cutting.

3.3) Propagation of Teak for Clonal testing: Part II (Cutting)"

An article entitled "Propagation of Teak for Clonal testing: II (Cutting)" were published as co-author with Somporn Khumchompoo was published in ITTO - Teak Mekong Newsletter June 2021 - Volume 3(4) in ITTO - Teak Mekong Newsletter June 2020 - Volume 2(3). The content of the article are about rooted cutting of teak conducted at Maegar Silvicultural Research station. Duration of shoots harvesting are reported. Figure of rooted cutting procedures are illustrated.

Photo 8. Rooted cutting techniques of teak.

3.4) Propagation of Teak for Clonal testing: Part III (Planting)"

An article entitled "Propagation of Teak for Clonal testing: Part III (Planting)" were published as co-author with Somporn Khumchompoo was published in ITTO - Teak Mekong Newsletter October 2021 - Volume 3(5). The content of the article is as following. It is important to harden the seedling prior to transportation. Procedure of safely transportation by pickup truck to protect seedlings from damage due heat from sun light and burn from wind are described. It is important to prevent messing up clone numbers, every seedling is tagged with clone number label. The same number must put into the same bag. Checking of clone number was done when loading the seedling up the truck and unloading at 3 planting sites. The sites were prepared by clear felling and slashed burning as practice in conventional forest planting. The treatment was 100 clones with 4 replications of 3 lines plot. Planting spacing was 4x4 m. Planting design of every site is CRBD. Allocation of clones was randomly sampling using CycDesign program of row-column design. The seedlings have already planted in 3 sites at ThungKwian and Thong Phaphum plantations and DonglanSilvicultural Research Station during August-September 2021. The ITTO Teak in Mekhong Project team visited the planting site at Krengkawia plantation on the 8th of October 2021. After visiting the field, the consulting team supervised and made some recommendations.

Photo 9. The ITTO Teak in Mekhong Project team visited the teak clonal test planting site at Krengkawia plantation on the 8th of October 2021

3.5) Improving teak resources in the Mekong

An article entitled "Improving teak resources in the Mekong" was submitted and expected to be published as co-author with Somporn Khumchompoo in next volumes of ITTO TFU Newsletter in mid-December. The content of the article is as following.

This article outlines some of the activities conducted to date under the project to improve the growing stock of smallholder teak-growers. First activity is the Joint Training Workshop on Teak Propagation Technique and Silvicultural Practice was convened at the Elephant Training Center, Lampang Province, Thailand. The aim was to increase skills and knowledge among forest officers and smallholders on teak propagation and genetic improvement, covering topics such as the basic genetic improvement of teak, the selection of materials for propagation, the principles of plant propagation, and teak propagation techniques. The intention was that the trainees would themselves become trainers in their own countries, capable of conveying knowledge and information to diverse stakeholders. Some participants in the workshop became instructors, supported by the ITTO project and conducted second round of training in their respected country. Some of the rained farmers in Ngao district were assisted by the project to expand their nurseries, which are now producing high-quality teak seedlings that can be sold at prices five times. The knowledge gained from the training were also applied to produce seedlings in clonal trial. Start with a single training event, the project has expanded knowledge and expertise in the five participating countries. More than 300 people now know to select good-quality teak trees for their plantings and how to propagate teak effectively; some local farmers are producing high-quality seedlings for sale. The improved performance of the new teak plantings will, in turn, serve to convince other farmers of the benefits of investing in good-quality planting stock to achieve better tree growth rates and form and, ultimately, higher prices for the timber.

3.6) 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 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 also provided 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#2 submitted first drafts of two chapters under session 3 (Silvicultural Practices and Teak Improvement) and session 5 (Research in Teak Genetics) which are:

Chapter 9: Teak Plus Tree Selection and Its Propagation Techniques Used in Thailand. (Annex1)

Chapter 21: Progress in Teak Improvement Program in Thailand. (Annex2)

3.7) Production of good-quality planting material of teak

First draft of final technical report on quality standards for teak planting material on a regional level suitable for the GMS countries titled "**Production of good-quality planting material of teak**" was prepared and submitted to the project manager and being edited by editor.

CONCLUSION

The **Consultant#2: Production of good-quality planting material** 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, four lectures were presented: 1) Presentation on "the Northern Seed Center and Ngao Silvicultural Research Station activities" on 25 April 2019, Lampang province. Thailand. 2) Presentation entitled "Teak Plus Tree Selection and Its Propagation Techniques used in Thailand" during 24-27 September 2019, Yangon, Myanmar. 3) Abstract of poster presentation entitled "Effect of serial harvesting of shoots on rooting ability of teak clones" at the XV World Forestry Congress (WFC 2021) on 2 to 6 May 2022. and 4) Paper titled "Progress on teak genetic improvement in Thailand" was presented at the second virtual monthly webinar meeting which was held on 25 February 2021.

Meanwhile, The Consultant#2 also contributed in five articles: 1) Policy Brief "Production of good-quality planting material" This policy brief published on Teak Mekong Newsletter June 2020 - Volume 2(3). 2) An article entitled "Propagation of Teak for Clonal testing: Part I (Budding or Bud-grafting)" was published in ITTO - Teak Mekong Newsletter June 2020 - Volume 2(3), Part II was published in ITTO - Teak Mekong Newsletter June 2021 - Volume 3(4) and Part III was published in ITTO - Teak Mekong Newsletter October 2021 - Volume 3(5). 3) An article entitled "Improving teak resources in the Mekong". and article in Book entitled "TEAK IN MEKONG FOR A SUSTAINABLE FUTURE" two chapters 4) Chapter 9: Teak Plus Tree Selection and Its Propagation Techniques Used in Thailand. (Annex1) and 5) Chapter 21: Progress in Teak Improvement Program in Thailand. (Annex2)

ANNEX 1

Chapter 9: Teak Plus Tree Selection and Its Propagation Techniques Used in Thailand

Chumnun Piananurak

Abstract

Characteristics to selection of Plus trees are dependent on the end use of the wood produced. Since teak fetches highest prices when usable as veneer, marine decking, furniture, etc., its stem form and wood texture are the most important traits for selection. Once plus tree is selected it could be propagated both by seed and vegetative means. Propagation by seeds is the easiest technique used by small farmers and, therefore, there is a need to establish more seed orchards to produce enough high-quality seeds for plantation. Teak can be vegetatively propagated by budding, rooted cutting and tissue culture each of which has both advantages and disadvantages and suitable technique should be used in order to gain the highest benefit. Budding technique by Open-two-flap was used for a long time until Chip-patch technique was developed which lends itself to very fast paced application. Budding is most successful when propagating mature material because budded shoots are rejuvenated and become suitable for carrying out rooted cutting or tissue culture. The technique is, therefore, recommended for application in first stage propagation of Plus trees subsequent to which other techniques can be used as needed. It is not advisable to use budded seedlings to directly establish clone bank, clonal test, or CSO due to the concerns of incompatibility and possible contamination of root stock plants if budded shoots have not been monitored properly. Rooted cutting is the cheapest, most successful, and easiest method to propagate juvenile material of teak but is less successful when mature materials are used. In the establishment of clone bank, clonal test, or clonal seed orchards, where a large number of clones but only a few seedlings per clone are involved, budding technique may be used to first rejuvenile mature materials and then undertake rooted cutting of the rejuvenile shoots to produce seedlings. In the case of mass production of elite plants, it is preferable to use tissue culture to produce juvenile stock plants for rooted cutting. When there are enough stock plants, rooted cutting is more useful than tissue culture.

Introduction

Teak is one of the most preferred species for plantation in Thailand creating huge demand for high quality planting stock across the country. Planting stock across the country is produced by three agencies, namely, farmers, Forest Industrial Organization (FIO), and the Royal Forest Department (RFD). A large part is produced by the Reforestation Promotion Office under the RFD producing almost 4 million seedlings per year. The second agency is small farmers in Lampang, Khonkan, Uttaradit and Phitsanulok provinces totaling more than 2 million seedlings. The last agency is the FIO whose central nursery for teak seedling production is located at Mae Moh plantaion, Lampang, producing 450,000 seedlings per year. Most of seed sources for farmers in Lampang are from unidentified seed sources in Serm-ngam district of Lampamg province. None of the small farmers use seed from improved seed sources such as clonal seed orchard. There

is one private company that uses teak seedlings from tissue culture of selected mother trees but their number is not known. The FIO produces 50,000 seedlings from its tissue culture facility using genetically improved material mostly for its own plantations but the rest of 400,000 seedlings produced by it for sale are from unidentified sources. The RFD uses mostly seeds from unidentified sources for its nurseries with only a small amount of seeds originating from clonal seed orchard that are largely used in its own plantations.

Thus, only a very small portion of teak seedlings use in Thailand is from genetically improved seed sources. Fortunately, in 2018 the Research and Development Bureau under the RFD initiated a scheme under the ITTO Teak in Mekong training program to produce 70,000 clonal seedlings from top ten Plus trees selected after full-sib progeny test for their growth and tree forms. These seedlings are meant for small farmers in Ban Huad sub-district group as stock plants for producing their own new high-quality seedlings. The ITTO Teak in Mekong training program not only benefits the project country partners but also a timely help for small farmers to learn and practice how to produce their own high quality seedlings.

Plus Tree Selection

Passing the discrete units of *inheritance*, or *genes*, from parents to offspring is a fundamental theory of *inheritance (*Miko, 2008).

Good offspring, therefore, must come from selected parent trees. In order to obtain the desired characteristic of trees in plantations the seedlings to be planted must be propagated from Plus trees. Characteristics of Plus trees selection are dependent on the end use of the wood produced from the plantations. Since teak fetches highest prices when usable as veneer, marine decking, furniture, etc., its stem form and wood texture are, therefore, important traits for selection. The criteria to select stem form are straightness, clear bole and axis (Piyapant, 2001). Trees that are straight with long clear bole, cylindrical axis, with less taper are desirable. Branch characteristics that affect stem form are size and angle. Smaller branch and perpendicular angle trend to better prune naturally resulting in longer clear bole. Wood texture could be identified by the pattern of bark. Straight stripe pattern determines the desired straight grain of wood inside while spiral pattern indicates twisted grain of wood that degrade the wood quality. Sample of plus tree and selection process is shown in Photo 9-1.

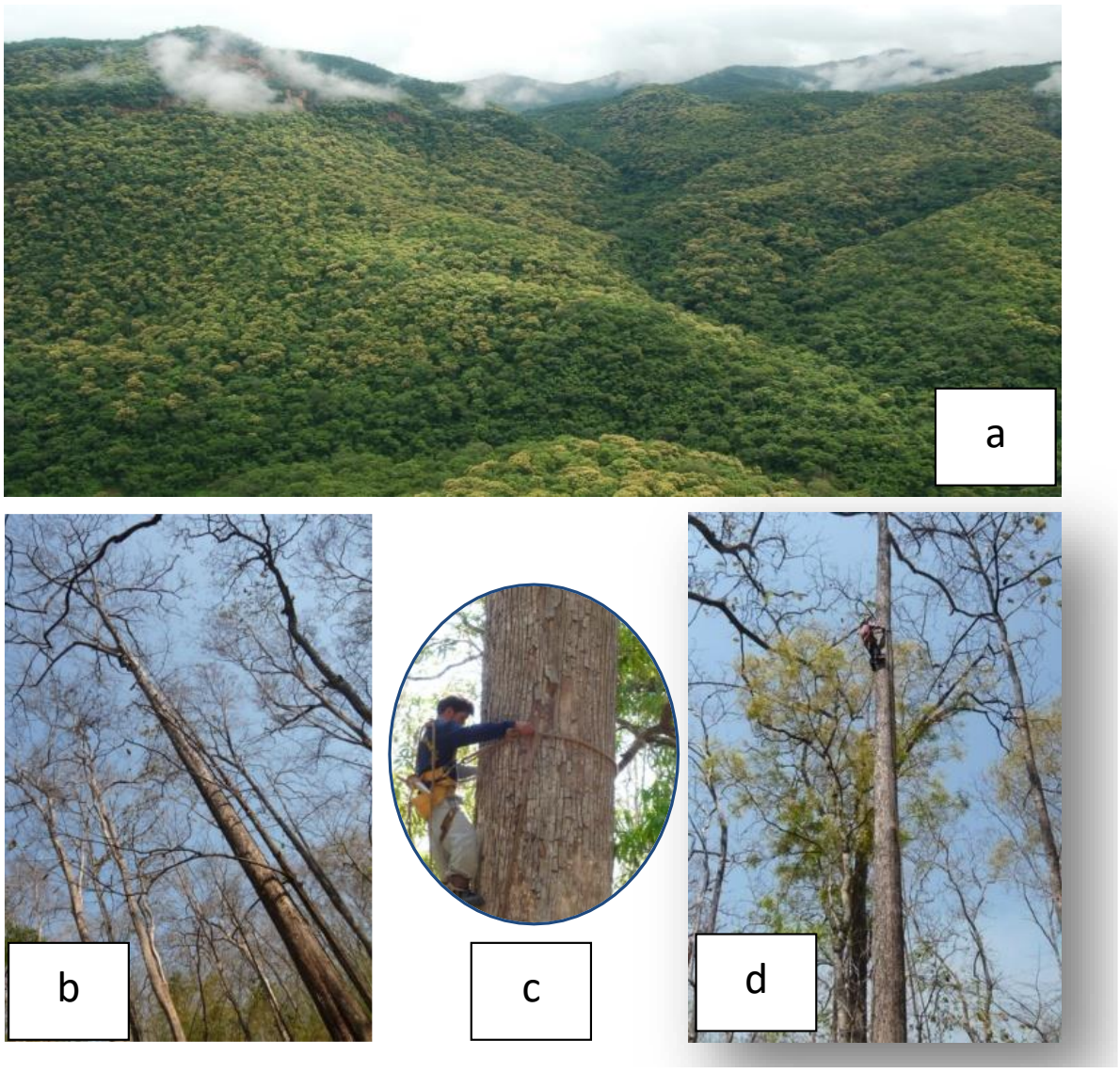

Photo 9-1 Plus tree selection
a) Natural teak forest as genetic resource
b) Sample of plus tree
c&d) Safety climbing to collect branch of plus tree for propagation

High buttress is more difficult to log when harvesting and also leads to increased harvesting losses in wood volume. No, or low buttress, is, therefore, the desired trait for selection. The buttress, however, often occurs where a tree grows on loose soil in order to provide stronger anchor which is a desired trait.

When selecting Plus trees the selector must look closely on the tree trunk from all directions, from near and afar. Health of the tree is also taken into consideration when selecting Plus trees. Trees with signs of borer attack or fungi attack are avoided.

Another important character is the growth of the tree which is easier while selecting Plus trees in old plantations that enable comparison of relative growth in candidate trees because they are the same age and in same environment, except for the border trees which grow bigger because of less competition. Selection from natural forest, on the other hand, is less reliable due to different environment the candidate plus trees encounters since germination until selection. The biggest and the highest tree is chosen giving due importance to the height up to which marketable timber can

be obtained. At least 15-meter commercial height is prescribed for Plus trees. The location of the Plus tree selected should be digitally recorded by using GPS and the information shared with field staff with instructions to avoid any damage to the tree and prevent its removal.

The phenotype of Plus tree selected is the outcome of its genetic traits x environment interactions during its growth. Therefore, after selection, the Plus tree must be examined to verify its higher genetic values in clonal tests. A total of 636 plus trees were selected in Thailand from both plantations and natural forests throughout the country. These Plus trees were propagated and planted in clonal banks, tested through clonal tests, established in clonal seed orchards, and tested for their progeny performance in the form of full-sib and half-sib progeny tests.

Propagation Techniques of Teak Used in Thailand

Propagation by Seed

Propagation by seed is the easiest technique to propagate teak because it is the natural method of propagation (Kaosa-ard, 1983a). Majority of plantation in Thailand were propagated by seeds using both bare rooted and containerized seedlings. Bare root seedlings are called "stumps" which are prepared from 1-year-old seedlings raised in seed beds by cutting the stem and lateral roots off retaining only the tap root with one or two buds (Lauridsen, 1973; Lauridsen & Kaosa-ard, 1973). When the climate is more stable and plantation site is far from motorable road, stump planting is more practical and popular. Nowadays, potted seedlings, produced directly from seeds or from stumps, are more often used due to variable weather. Potted seedlings can be produced from stumps sized less than 0.7 cm in diameter which is not suitable for direct planting. Direct sowing of seeds to produce potted seedlings is possible but needs greater care and carries high risk of failure in germination and therefore, not a popular method among small farmers.

Application in teak improvement program

Seeds are the product of the ripened ovule in mother, after fertilization by pollen from the father (Anon, 2019a). Genetic values in seeds are, therefore, inherited from both father and mother trees. The offspring performances vary depending upon what aspects are controlled by the parent gene. The progeny can thus both be worse or better than its parent in some specific respects. This fact is utilized in tree improvement when better off springs are selected for next generation the seeds of which are the end products of the program and are used to produce seedlings for the establishment of seedlings seed orchard (Piyapant, 2001). Seeds from these seed orchards then become the main genetic materials for plantation.

Vegetative propagation

Seedlings propagated using other parts of plant besides seed, or cloning, will maintain the same genetic characteristic as mother plant (Anon, 2019b). These techniques, therefore, does not improve genetic traits of plants but can be used to multiply the already improved ones. There are many techniques to vegetatively propagate teak such as budding, rooted cutting and tissue culture. Each technique has advantages and disadvantages and, therefore, suitable technique should be used in order to gain the highest benefit.

Budding technique is the method that uses grafting scion bud onto stock plant. The new plant is developed from the scion bud using root system of the stock plant. T-budding was the first technique used in Thailand before Forkert and Open-two-flap techniques were developed. Open-two-flap technique is used with bigger and more succulent buds from the clone bank. Open-two-flap was very successful and used for a long time until Chip-patch technique was developed which lends itself to very fast paced application and is mostly in use now

(Keiding & Boonkird, 1960a; Keiding & Boonkird, 1960b; Bryndum, 1969; Hedegart et al., 1974; Sumantakul, 1980; Kaosa-ard, 1983b).

Planting stock for teak budding

At the beginning of the Teak improvement program stock plants were planted in clone bank and clonal seed orchard 1 year prior to budding procedure. The success was very low and uneven. Later stumps of 1-year old seedlings were successfully used as planting stock (Hedegart et al., 1974). Size of stump should be the same size as scion. To prepare stumps for budding, 1–3-year-old-seedlings are taken from seedling beds, lateral roots pruned, and stem topped at about 20-25 cm height. Chip-patches, about 3-5 cm long, are slit just above root collar and grafted with scion bud patch (Pianhanurak et al., 1996). Stump can be stored up to 3 days covered with moist sand before budding (Piyapant, 2001).

Scion bud

The most suitable bud for grafting is the one that just starts to sprout. Selection of Plus tree, therefore, must be done during March to April when the bud of teak starts to sprout (Hedegart et al., 1974). Buds taken from newly flush shoots (1-2 years) are easier to graft and the buds taken from outer crown produce shoots that shows more twig characteristic than the one taken from inner crown (Boonkird, 1964). Branches that contain suitable buds are harvested and brought back to nursery for grafting, kept in a sack and stored in cool place. They can be kept under moist rice husk for a month without damage (Piyapant, 2001). When grafting on root stocks, the buds are cut in the same shape and size as the chip-patch of the root stock and then placed on to the slit part of the stock. The two parts are then tied together by plastic sheet leaving only the bud exposed (Pianhanurak et al., 1996).

Raising of budded stumps

After planting the budded stumps in containers, the buds are covered with a small plastic bag to prevent moisture loss from the bud (Pianhanurak et al., 1996). The budded stumps are then raised in a nursery with 50 percent shade (RFD, 2013). Watering must be done regularly until the buds sprout in about 1-3 weeks and all shoot sprouts must be removed from the root stock. When the scion buds sprouts, the plastic cover bag should be removed to let the new shoot grow freely and prevent sunburn (Piyapant, 2001). The budding technique is shown in Photo 9-2.

Photo 9-2 Teak budding process by patch grafting techniques
a) Preparation of root stock from 1 year-old bare root seedlings
b) Graft scion bud patch onto slit stock and tie with plastic rope
c) Cover the budded seedling with plastic bag and planted in media then kept in nursery
d) Remove plastic bag after budded sprout, and get rid of buds sprouted from root stock

Disadvantages of budding technique

Incompatibility due to the different growth rate of stock plant and scion, or fungal infection at the joining part, sometimes slow down the growth rate and even kill the scion shoot (Piyapant & Pianhanurak, 1994). Regular removal of sprout from stock plant must be carried out to make sure no sprout from stock grows over the scion shoots.

Application of budding technique in teak improvement program

Thailand has often used budding technique to establish clone bank, seed orchards, and clonal test but where rooted cutting and tissue culture of teak is possible, budding technique is not preferred. Budding technique is not recommended for propagation in a clonal test because the root system does not belong to the tested plant.

Rooted cutting: A piece of the stem or root of the source plant is placed in a suitable medium such as moist soil. If the conditions are suitable, the plant piece will begin to grow as a new plant independent of the parent, a process known as striking. A stem cutting produces new roots, and a root cutting produces new stems (Anon, 2019c). In teak it is more difficult to induce root in mature branches than in juvenile material. For propagation by cuttings of old Plus trees, the branch

identified for cutting must first be rejuvenated

(Pianhanurak et al., 1996) through serial budding, tissue culture, serial cutting, or hedging. For maintaining juvenile nature of stock plants, hedge orchard of teak must be planted in small plastic bag instead of planting in the field (Pianhanurak & Pianhanurak, 2000; Pianhanurak & Pianhanurak, 2002; Pianhanurak, 2002; Piyapant, 1999). The quality of cut material in the controlled environment is a critical factor affecting rooted cutting of teak. The cutting materials must be juvenile, age not more than 4 weeks after pruning, size of stem less than 0.5 cm in diameter, leaves thin, soft and covered with hair (Pianhanurak, 2002). To prepare cuttings, leaves are trimmed to about one-third size to reduce transpiration, then apply rooting hormone for 10 second before being kept in rooting media.

Environment control

Non-mist propagators consisting of bamboo frame covered with plastic sheet are used to control relative humidity of the air around the cuttings. Moisture content in rooting media is controlled by watering until very wet before striking the cutting. Temperature is controlled by providing shade by a plastic sheet around the rooting chamber and spraying water during the day when the weather is hot. It is more desirable to do cutting in rainy season since the weather is suitable for plant growth. If nothing goes wrong roots will develop after one month (Pianhanurak, 2002). The rooting procedure is illustrated in Photo 9-3.

Photo 9-3 Rooted cutting processes of teak from rejuvenated materials
a) Preparation of rejuvenated shoots by trimming off half leaves and applied rooting hormone
b) Preparation of rooting media in non-mist propagators
c) Temperature and humidity controlled during rooting period
d) Gradually remove shade to get full sunlight when the seedlings establish

Application of rooted cutting technique in teak improvement program

After the success of the rooted cutting of teak, it was applied in many occasions.

1. Prepare seedlings for 5 sets of clonal tests which aim to evaluate the genotypic value of plus trees by planting a range of them in the same environment (thus removing "environment" as a factor in determining their physical properties). The genotype ×environment interactioncan be examined by replicating the clonal test at different sites. Ultimately, the top-ranking clones can be selected and propagated, for either deployment in plantations or additional improvement.

2. Clone bank where collection of plus trees are planted, plus trees number 1 – 400 were propagated by budding technique, from number 401 and so on were propagated by cutting technique. 3 clone banks that established in 2009, the seedlings were also propagated by rooted cutting.

3. The technique was used in combination with tissue culture to produce special teak that harvested to build the Giant Swing in 2006. 200,000 seedlings were tissue cultured as parent materials then propagated by cutting to produce up to 1,000,000 seedlings of the special trees to give out to people.

4. At present when new improved materials were selected, tissue culture is used to produce stock plants then cutting is the main activity to mass propagate teak for distributing seedlings to farmers.

Tissue culture is a technique in which small tissue pieces or organs are removed from a donor plant and cultured aseptically in a nutrient medium (Anon, 2019d). There are four steps to do tissue culture of teak. First step is sterilizing of explants into initial stage medium. Second is the initial stage when the tissue adjusts to new environment to be ready for the multiplication stage and rooting stage. Third is the multiplication and rooting stage with a growth hormone added to the media when the tissue becomes plantlet ready to be multiplied or rooted. The last stage is transferring of plantlet to potting soil for further growth in the greenhouse as normal plants (Kyte, 1990).

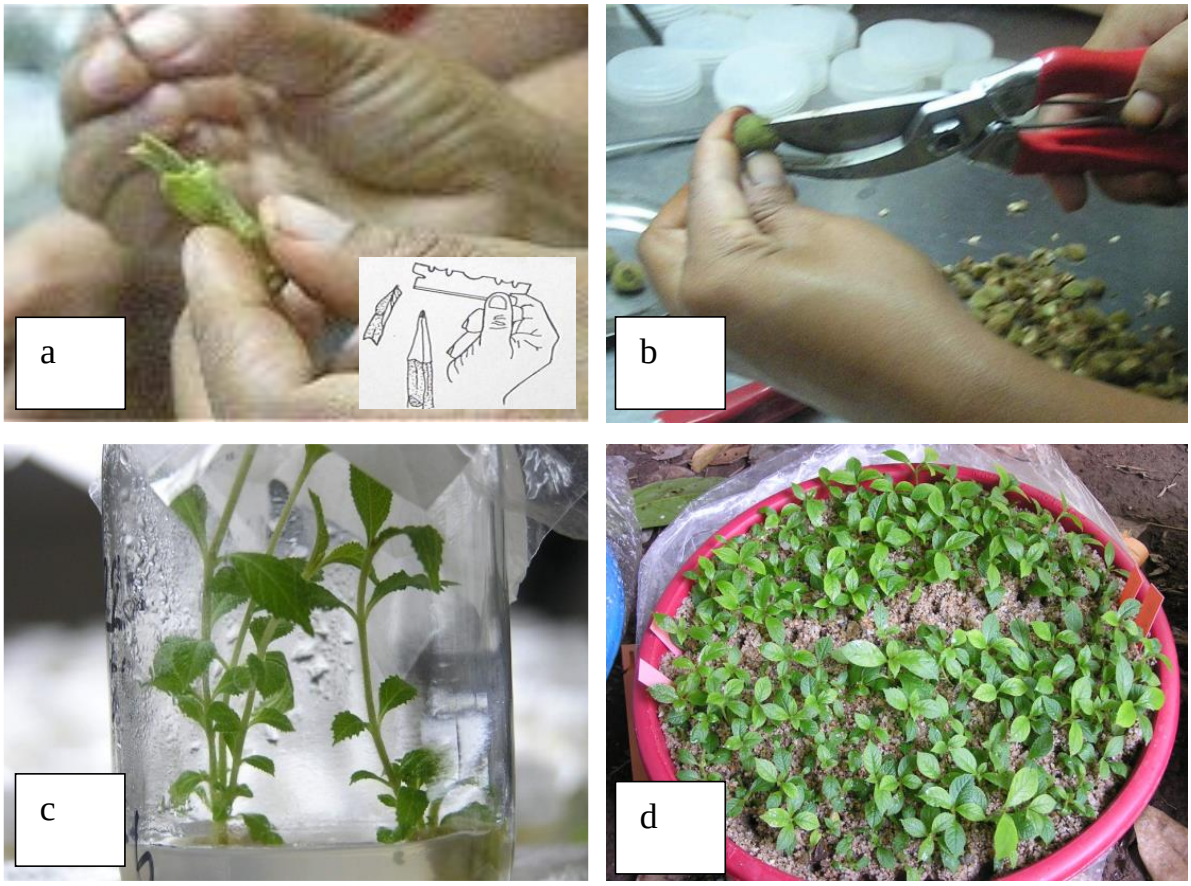

Photo 9-4 Tissue culture processes of teak
a) Sterilize technique of young shoot
b) Sterilize technique of young seed
c) Teak tissue in multiplication stage
d) Out planting of plantlets to nursery

Explant of teak could be young seed, mature seed, axillary bud or shoot meristem. Each explant needs different technique to sterilize and manipulation during initial stage. Once the tissue reach multiplication stage they all need the same treatment (Pianhanurak, 2003). Medium for culturing teak is Murashige and Skoog (MS) media (Murashige. & Skoog, 1962) with Benzene Adenine Purine (BAP) 0.5 mg, Kinetin (Kn) 0.25 mg per liter and 7 percent agar for multiplication and without hormone or with Indole Butyric Acid (IBA) 1 mg or Naphthalene Acetic Acid (NAA) about 0.5 mg per liter in rooting stage (Pianhanurak, 2003) When transferring to nursery, however, the plantlet does not need root. It is easier and more effective to cut plantlet above agar level and root the plantlet in planting media. The same environment control as rooted cutting is required for transplanting the plantlet. The process of teak tissue culture is illustrated in Photo 9-4.

Application of tissue culture technique in teak improvement program

The technique requires skill, experience, high technology equipment and high cost. Plant to be propagated by this technique should have high genetic value and selected for planting on large scale since mass production will reduce its cost. There are also risks due to cleanliness of the laboratory and stabilization of electric supply to the laboratory. If these risks are not controlled, the lab may lose a lot of tissue to contamination with microorganisms. It is suggested to use tissue culture to produce juvenile stock plants for rooted cutting.

Lessons Learned and Recommendations

Plus tree selection is the most important step of tree improvement program. Criteria and standard of selection should be set up carefully based on each country's situation and expectations. The number of Plus trees to be selected should be as large as possible depending on the budget and human resources. Selection should be done throughout the available genetic resources, even exchanging the genetic material across the countries of the Mekong sub-region, in order to provide widest genetic base to the improvement program. Training in vegetative propagation by budding technique should be organized before the selection of Plus trees so as to collect materials for propagation as soon as a Plus tree is selected deep in remote forests to avoid frequent visit to the Plus tree again soon after selection.

Propagation by seeds is the easiest technique and it plays an important role in the improvement program as small farmers use this technique to produce their seedlings. It is, therefore, recommended to establish more of high quality seed sources such as seed orchard to produce enough high quality seeds for plantation. Often small farmers use seeds from unidentified seed sources even as seeds from Clonal Seed Orchards (CSO) remain stored in seed centers until their viability is lost. To promote use of CSO seeds, they should be given free of cost, or at very low costs, to the farmers.

Teak can be vegetatively propagated by various techniques. Budding is the most successful when propagating mature material because the budded shoots are rejuvenated and become suitable for carrying out rooted cutting or tissue culture. The technique is, therefore, recommended for application in first stage propagation of Plus trees subsequent to which other techniques can be used if needed. It is not advisable to use budded seedlings directly to establish clone bank, clonal test, or CSO due to the concerns of incompatibility and possible contamination of root stock plants if budded shoots have not been monitored properly. This is best carried out in combination with rooted cutting or tissue culture. The main purpose of budding is to rejuvenile mature materials before exposing to cutting or tissue culture for large scale multiplication of planting stock.

Rooted cutting is the cheapest, most successful, and easiest method to propagate juvenile material of teak. It is less successful when mature materials are used. In the establishment of clone bank, clonal test, or clonal seed orchard where a large number of clones but only a few seedlings per clone are involved, it is recommended to use budding technique to first rejuvenate mature materials and then undertake rooted cutting of the juvenile shoots to produce seedlings. In the case of mass production of elite plants, it is recommended to use tissue culture to mass produce juvenile stock plants for rooted cutting. When there are enough stock plants, rooted cutting is more powerful than tissue culture.

Conclusion

Selection of plus trees should be done carefully and thoroughly to cover all available resources. Criteria and standard for selection must be set up properly to get the right trees for improvement program. Using the right technique of propagation in every step of improvement program is the key to the success of genetic improvement of teak. Budding technique by Chip-patch technique is the most successful when propagating mature material. Budded shoots are rejuvenated and become suitable for carrying out rooted cutting or tissue culture, the technique is, therefore, recommended for application in first stage propagation of Plus trees subsequent to which other techniques can be used as needed. It is not advisable to use budded

seedlings to directly establish clone bank, clonal test, or CSO due to the concerns of incompatibility and possible contamination of root stock plants if budded shoots have not been monitored properly. Rooted cutting is the cheapest, most successful, and easiest method to propagate juvenile material of teak but is less successful when mature materials are used. In the establishment of clone bank, clonal test, or clonal seed orchards, where a large number of clones but only a few seedlings per clone are involved, it is recommended to use rooted cutting of the rejuvenile shoots to produce seedlings. In the case of mass production of elite plants, it is preferable to use tissue culture to produce juvenile stock plants for rooted cutting. When there are enough stock plants, rooted cutting is more useful than tissue culture.

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ANNEX 2

Chapter 21: Progress in Teak Improvement Program in Thailand

Chumnun Piananurak

Abstract

Teak genetic improvement in Thailand began in 1965 under a bilateral agreement between Thailand and Danish governments. Plus tree selection is the first and most important step in genetic improvement program. Guidelines for selecting and criteria for selection were set up based on of four aspects of growth, stem form, wood quality, and the health of the tree and a total of 636 Plus trees were selected. Of these 509 Plus trees were planted in 5 clone banks across the country. Since in selecting Plus trees only phenotype is evaluated clonal tests are needed to evaluate genotypic characteristics. Three sets of clonal test were conducted, the first one using budding techniques for propagation for 100 clones and tested at one site. Second set of clonal test was conducted using rooted cuttings for vegetative propagation for 400 clones at 4 sites. The last set of 100 clones has recently been established as part of the ITTO-Mekong Teak project in 2021. For improved teak seeds Clonal Seed Orchards have been set up using 256 Plus trees.

Progeny tests using full-sib progeny and half-sib progeny were employed to identify trees of better genetic quality. These high-quality teak seeds are now available for use by farmers for producing high quality teak timber.

Introduction

Thailand started its teak improvement program under a bilateral agreement between Thailand and Danish governments in January 1965. A teak improvement center, known as Ngao silvicultural research station, has been established in the Ngao District in Lampang Province in the Northern part of the country to run teak improvement program under this project. At the beginning of the project some Danish experts were assigned to work closely with Thai researchers. They helped set up the teak improvement program for Thailand as shown in the flow chart (Figure 21-1) which is used as a step wise guidance for teak improvement in the country. The progress of each step is reported here in this article.

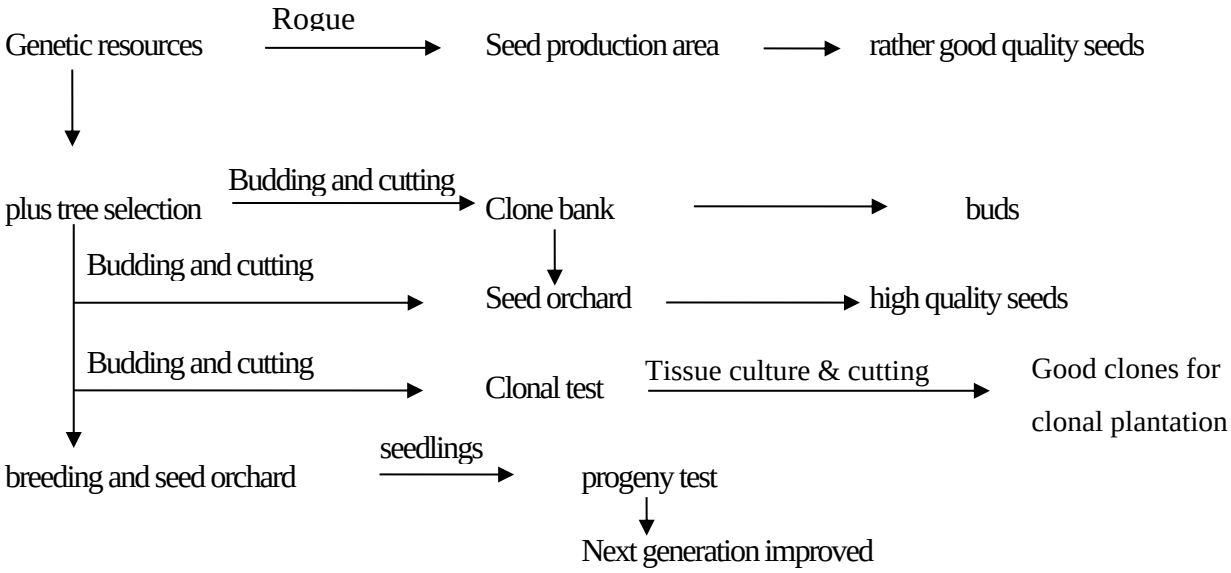

Figure 21-1 Teak improvement program in Thailand (Kaosa-ard & Chanpaisaeng, 1992)

Plus Tree Selection

Plus tree selection is the most important step. If the selection is wrong, it will ruin the whole program so the plus tree must be intensively selected. The selection of the plus tree is aimed at getting the highest possible genetic gains in quickest possible time and at least cost while maintaining a wide enough genetic base to ensure that the genetic gains will continue to increase over generations.

In selecting mother trees for breeding, the same principle is used to select trees with wanted characteristics. The selected trees are then used as parents in breeding and production of good quality seeds based on the hypothesis that parents with good genetic traits will always pass good traits to their offspring.

Some important advantages of using selected plus trees in the forest plantation work.

1. Trees in plantation have a good shape, straight stems with few knots, which make the cost of logging for hauling and transporting cheaper.

2. Lowered losses during processing and manufacture.

3. Rotation is shortened because the trees grow faster, resulting in a faster return on investment.

4. Reduces investment in planting as trees can be planted at wider spacing.

5. This makes investments in consequence industries less cost.

6. Get better wood quality such as high density and straight wood grain etc.

Forest breeders should choose only the most important characteristics in selection of plus trees, namely, high economic values and positive correlation with other traits. Characteristics that are commonly taken into consideration when choosing a plus tree are good growth, round stems, branches that prune naturally and are medium to small compared to the stems in proportion and shape, good resistance to diseases and insects, resistant to drought conditions, resistant to cold conditions, late flowering, good wood quality. Sumantakul (1999) has set up guidelines for selecting Plus trees as follows:

1. Choose a forest stand or a forest plantation that consists of trees that are naturally tall and well grown, most tree trunks are round and straight, branches are naturally pruning and perpendicular or nearly perpendicular angles to the trunk. It may be called a Plus stand.

2. The Plus stand should be located in an area with conditions similar to the area that future forest plantation will be planted.

3. Do not choose from plantations that use seeds from sources that are not well adapted to the environment where plantations are to be raised in future.

4. Selection should be from a tree stand that is largely of the same species.

5. The selected trees stand should not have been logged before and forest plantation that has been thinned should not be selected except for mechanical thinning.

6. The size of the plus stand is not limited, but it must contain enough candidate trees and comparison trees.

7. Only one mother should be chosen if the group is small. This is to avoid inbreeding of the selected mother trees.

In Thailand, the criteria for selection consist of four aspects. First is growth which is diameter at breast high, and height especially commercial height. In natural stand, the set standard is at least 15 meter commercial height but in plantations it may be shorter. Second is stem form which are clear bole, small branches, straight axis and low buttress. Third is wood quality for which it would be good to check wood color and density by using wood borer and pylodyne. Wood grain is usually indicated by bark pattern with straight strip bark pattern indicating straight wood grain inside. If it is spiral bark the wood grain will be twisted. The last is health of the tree. Around the candidate tree it must be checked that there is no sign of pest and disease. Sumantakul (1999) suggested using a scoring method and set up standard guide line to select plus tree using tree selection form in which information of each plus tree is recorded.

The plus tree selection of teak is done in dry season when the forest is easier to walk through and it is clearer to look at the tree form. Other reason is that in dry season the buds start to sprout which is the most suitable stage to be grafted. It is difficult and costly to go to the forest to get to the plus trees again and again and, therefore, the branches of Plus trees must be collected during Plus tree selection process itself and taken back for propagation to conserve their genetic materials. Clone number, called V number, are given during selection itself for each tree, information are recorded in Plus tree record form and photograph are taken. While taking photograph V number is placed on a sign board on the tree and genetic materials taken from each plus tree is labeled accordingly.

Clone Bank

Up to now a total 636 Teak Plus trees have been identified and numbered in Thailand under the teak improvement program. The Plus trees are scattered in areas which are mostly difficult to access, such as deep forests, on mountains with no road access. Each plus tree is far away from each other. After the selection program is over, it is difficult and inconvenient to return to do seed or scion collection. In addition, most of the selected trees are good quality and, therefore, specially prone to illegal felling causing the loss of selected trees. So it is wiser to take genetic material of plus trees to plant at a safe place that called “Clone Bank” which serve as multiplication garden as well.

Objectives of clone bank.

The establishing a clone bank of teak plus trees has the following objectives:

1. To conserve Plus tree genetic material in safe places.

2. To conserve teak Plus trees genetic material from around the world to be used

as genetic resource whenever needed. The genetic resource can be used for further improvement program such as in seed orchard, clonal test, or even planting a forest plantation.

3. To act as multiplication garden where branches of Plus tree can be taken for propagation and used for further improvement program avoiding the need to go back to the forest for Plus tree genetic material.

4. To copy all genetic traits of plus trees by using vegetative propagation.

5. To conserve not only teak plus trees but also some that have a special history, such as a biggest teak in the world, or teak that is resistant to insects or pests.

6. To facilitate the management of selected Plus trees.

Establishment and management of clone bank

Planting materials are from vegetative propagation like budding or cutting. Spacing 2x2 m^2 is suitable with same clone planted in the one row. Usually, 10 propagates per clone are planted.

1. The branches taken from plus tree are propagated by budding in nursery in order to rejuvenate the materials. The rejuvenile shoots are then propagated by rooted cutting.

2. Planting seedlings in rows, one row for one clone and each row contains about 10 seedlings (ramet). Lay out of clone planting should follow sequence number for ease in future management. Spacing of 2x2 meters is convenient for operational reasons.

3. It is important to emphasize that in front of each row, a ferroconcrete post is buried leaving about 50 cm. above ground and on each such post the V no. of the Plus tree is carved. Wooden posts are not suitable as they tend to degrade early.

4. Maintenance of the garden by watering, weeding, fertilizing is carried out as in ordinary plantation. In the case of budding technique for propagation, paint (preferably red or bright) is used to mark the part of the trunk where stock and scion are joined. Regular monitoring is done and shoots that sprout below the joint are removed. This activity must be carried out every year.

5. Trim the canopy to make the stems shorter and produce more branches. This is for the convenience of collecting branches and maintaining juvenility of the bud, which improves the ability of vegetative propagation. This needs to be carried out at least once a year.

Table 21-1 Information about Clone Banks in Thailand

No.	Location[#]	Area (ha.)	No. of clone*	Established year
1.	Ngao SRS	5.76	396	1965-2019
2.	Maegar SRS	0.5	113	2002-2003
3.	Phitsanulok SRS	4.00	438	2009
4.	Donglan SRS	4.00	438	2009
5.	Thongphapoom SRS	4.00	438	2009

[#]SRS stand for Silvicultural Research Station *Same clones were planted at many sites.

Information on the clone banks is presented in Table 21-1 above. The total number of clone in clone bank is 509 clones. All the 636 Plus trees are not represented in the clone banks as some plus trees were discarded during reselection or died during propagation.

Photo 21-1 illustrates concrete post in front of every plant row indicating clone number and management by pruning every year. Trees in the clone bank are bushy because they are cut every year. There are 5 clone banks in Thailand as shows in Table 21-1. The original clone banks were planted in Ngao SRS and Maegar SRS in the north of the country. In 2009 three more clone banks were established at Phitsanulok SRS, Donglan SRS, and Thong phapoom SRS in different parts of the country to reduce the risk of loss of precious genetic material.

Photo 21-1 Clone bank at Mae gar SRS

Clone Test

The clonal test is one of the important tasks of teak improvement program. The test aims to evaluate the genotypic value of the Plus trees for breeding and further propagation. When we select Plus trees we can see only phenotypic traits of the trees. Phenotype is the observable physical characteristic of a tree determined by the genotype interacting with the environment in which it is grown. In clonal test the objective is to evaluate genotypic value of Plus trees by planting in the same environment. Thus the comparative phenotype across Plus trees observed in clonal test is controlled by genetics alone. We also evaluate genotype and environment interaction on plus trees by testing at many sites. Plantlets from different Plus trees are taken through vegetative propagation and then planted together for testing in the same area. The test can be conducted in many sites to evaluate genotype and environment interaction.

Objectives of teak clonal testing

1. To select the best individual for further improvement step or to build a seed orchard or clonal plantation.

2. To assess the genotypic value of existing Plus trees or clones to be used as indicators for re-selection the Plus trees

and perform genetic thinning primarily in the teak seed orchard.

3. To assess broad-sense heritability and to study genetic correlation between characters of teak from the tested clones.

4. To assess the genotype and environment interaction of the existing plus tree or clones in order to be used as an indicator for the selection of suitable clones for planting teak clonal plantation, either locally or in multiple sites.

How to conduct teak clonal test

The plantlets used in the test must be asexually propagated. A suitable method is the rooted cuttings although tissue culture is possible but is not preferred because it is more expensive. The test area must be located in at least 3 different sites in order to explore the genetic and environmental interactions. Planting in randomized complete block design consists of 100 treatments (Plus trees), 3 sites with each site having 4 replications and each replication consisting of 3 plants. Plus trees from the same source are not placed close to each other because if the experimental plot is later modified to a clonal seed orchard, Plus trees from the same source will spread throughout the plot. The total number of trees planted in each site in Thailand is 1,200 trees, using a spacing of 4 x 4 m, with the buffer zone was planted with 2 rows of teak trees surrounding the plot.

After the test plot has been planted, check the survival percentage during the first three months and replant once every month. Maintenance of the plots involves weeding twice a year, rigorous fire protection and forest fire prevention. Measurements of growth in diameter and height are recorded every year. Final evaluation is performed at the age of 20 by measuring growth and shape which consists of straightness of the trunk, rupture of the trunk, branching characteristics, size of branches, flowering, as well as the health traits including survival and stem damage.

Teak clonal test in Thailand

The timeline of teak clonal test in Thailand can be summarized as shown in Figure 21-2. From the timeline and information shown, the test can be divided into 3 sets.

First clonal test was planted in 1988 using budding as the propagation technique. Testing was conducted at Ngao SRS. The treatment was 100 clones with 6 replications of 2 trees plot. Planting spacing was 3x3 m. Some superior clones from this test were used for clonal propagation, for plantation and for selecting mating-pairs in full-sib progeny test. There are controversies about budding technique used for this test since the root system does not belong to the tested clone. Root system plays an important role in the tree growth and, therefore, growth of the tested trees is not affected solely of the clones themselves.

Second set of clonal test was done using rooted cutting of teak once the practice had been practiced and well documented (Pianhanurak et al., 1996). It was established at 4 sites at Thong Pha Poom SRS, Kham Phang Phet SRS, Song Khla SRS and Ngao SRS. Each site has 4 sub-sets planted in 2000, 2001, 2003 and 2006 except Ngao SRS that has only 1 sub-set planted in 2005. Propagation technique used was budding for rejuvenation from which shoots were taken for rooted cutting. Each sub-set testing plans are the same except for testing different clones. The treatment was 100 clones with 4 replications of 3 line plot. Planting spacing was 4x4 m. Planting design of every set is CRBD.

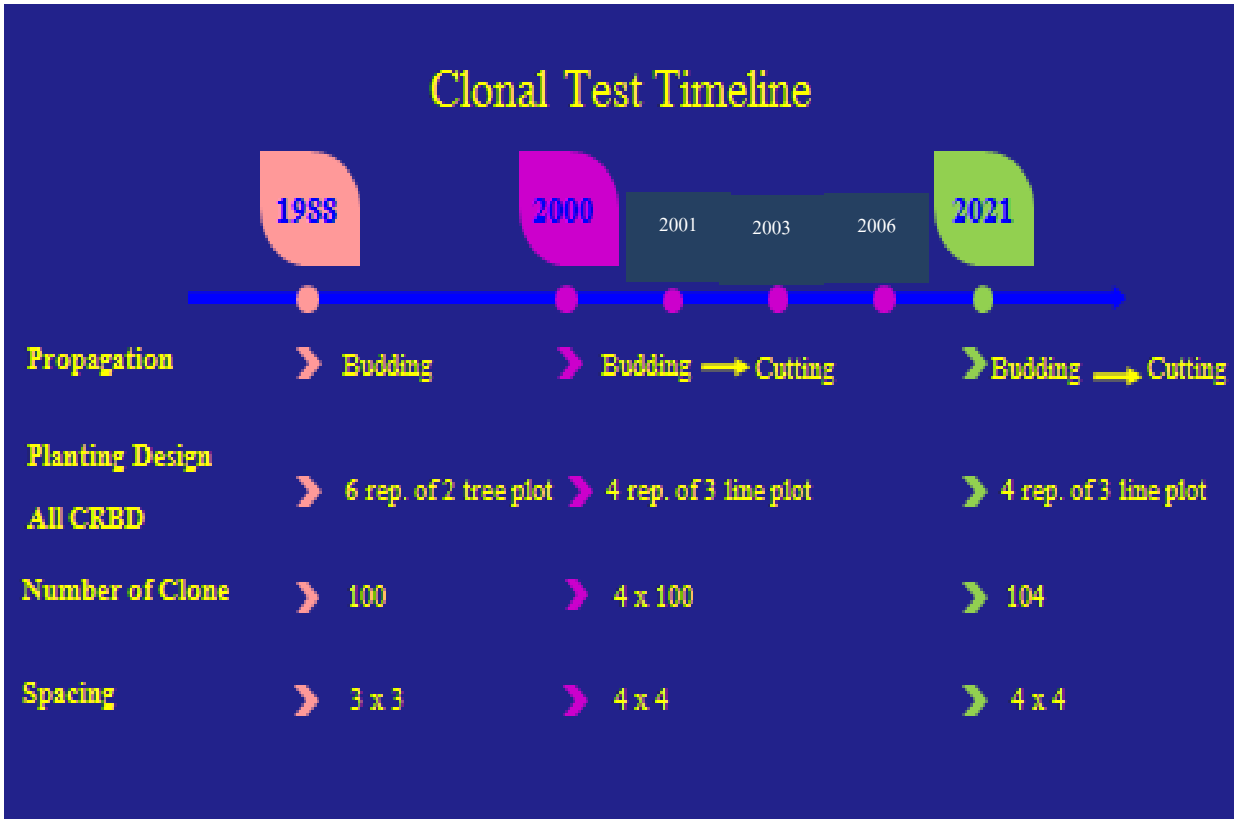

Figure 21-2 Teak clonal test timeline and the testing information

The 2000 test plots at 3 testing sites, namely, Kanchanaburi, Songkhla and Kamphangphet were evaluated twice at 5 and 10 year age (Anon, 2013). One testing site could not be evaluated due to fire damage. The first result at 5 years old showed that height and DBH of tested clones were statistically significantly different at different sites establishing the effect of interactions between site and clone on growth of plants. The second results at 10 years age confirmed the preceding evaluation by showing the same results. There were only 2 stable clones that grew well at all sites. The 5 best clones in each site were separately selected to be the suitable clones for promotion among farmers.

Another set, sponsored by the ITTO Teak in Mekong Project, was planted in 3 sites at Thung Kwian, Krengkawia plantations and Donglan SRS in 2021. Propagation technique used was budding for rejuvenate materials followed by taking the shoots for rooted cutting. The tested clones consist of the clones which have not been tested in the second set in addition to 10 superior clones selected in the 2000 test. The treatment was 100 clones with 4 replications of 3 line plot. Planting spacing was 4x4 m. Planting design of every set is also CRBD. The locations of clonal tested sites are shown in Figure 21-3.

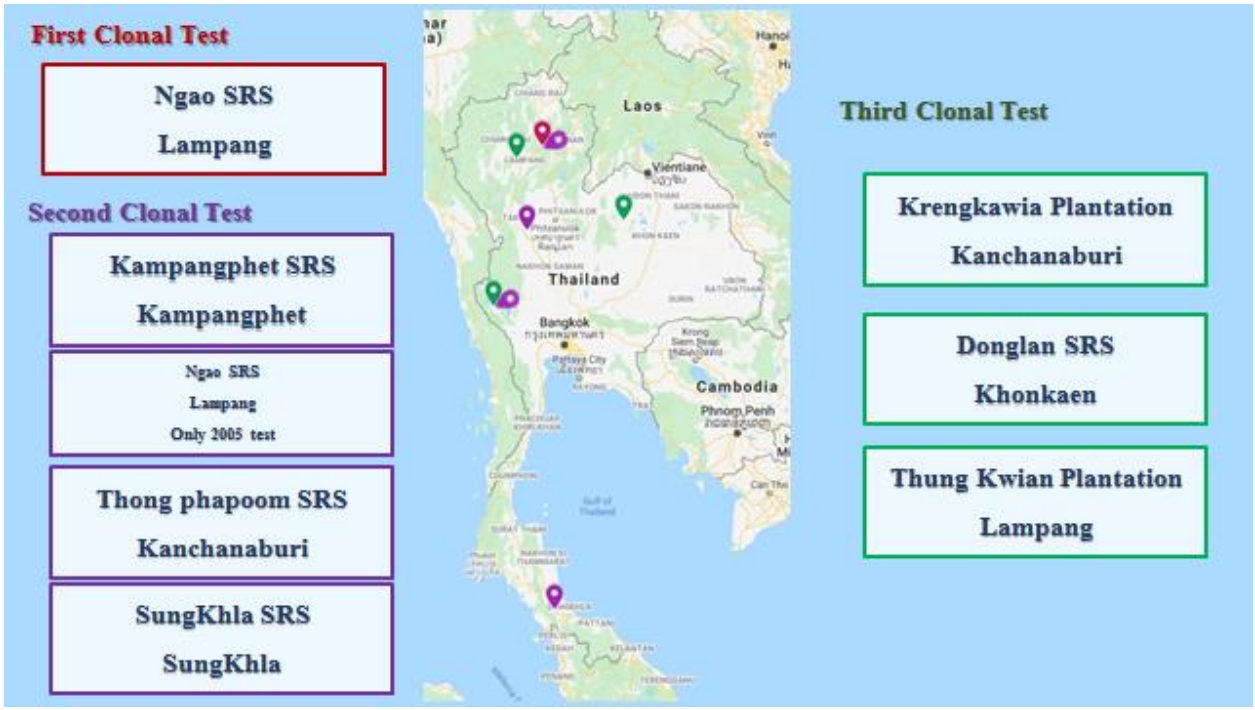

Figure 21-3 Locations of 3 sets of clonal tests of teak plus trees

Seed Orchard and Breeding Orchard

Establishing a seed orchard is a continuation step from the selection of Plus trees by bringing the selected father and mother plants to an orchard to produce good seeds. A seed orchard is defined as an area where seeds are mass-produced to increase the genetic quality as quickly and inexpensively as possible (Zobel et al., 1958). It is a plantation of trees with the requisite genetic characteristics planted at a distance from natural or planted forests of the same species. It is managed to achieve high and consistent seed yields that are easy to harvest.

Seed orchards can generally be divided into two types: clonal seed orchards and seedling seed orchard (Zobel et al., 1958). A clonal seed orchard is a seed orchard created by using plantlets from asexual propagation such as budding, cutting or grafting from selected plus trees. Trees in the orchard inherit all the genetic traits of the mother trees. Each seed orchard would not be less than 50 clones and planted by random planting positions (Sumantakul, 1999). A seedling seed orchard is a seed orchard created by using seedlings collected from the selected Plus trees. At present only clonal seed orchards have been established for teak in Thailand.

Characteristics of teak seed orchard

The teak seed orchard must have the following characteristics (Khaosa-ard, 1983):

1) Seedlings used in clonal seed orchard must be selected clones propagated by asexual method.

2) A seed orchard must have a layout map showing the number of clones planted as well as their locations in the orchard.

3) In a seed orchard the plant spacing should be more compared to normal forest plantation to allow the trees planted to fully expand their canopies to maximize seed yield. For teak, the spacing used is generally 10 x 10 meters.

4) A teak seed orchard should be at least 1 to 2 km away from natural teak forest and teak plantations to prevent cross breeding by pollen from outside the orchard.

5) Establishing a seed orchard requires special care compared to a general forest plantation. Fertilizers may be applied to

accelerate tree maturity to hasten fruiting as well as increase seed yield. Weeds should be cleared to make it easier to collect seeds, insect and disease control measures should be undertaken.

6) In Thailand collecting of seeds in seed orchard is done by climbing up and collecting from individual trees. Seed collection is usually done in February before seed fall. Seed extraction and cleaning are carried out manually by beating, sieving and grading.

Data collected on location, topography, meteorology, planting method, tree growth, orchard management, seed production, seed quality, and soil properties of clonal seed orchards (CSO) in Thailand and reported in Piananurak (1995) is presented in Table 21-2. There are 22 CSOs in Thailand hosting a total of 256 clones. Six of these CSOs are under the administration of Royal Forest Department while the rest fall under the control of the Forest Industry Organization where no seed collection is being done at present.

Table 21-2 Information of CSO in Thailand

Sr.	Name of CSO	Area (ha.)	No. of clone	Seed productivity (Kg/yr)	Established year
1.	Mae Gar SRS	175	193	950	1965
2.	Lansang SRS	127	44	-	1965 (canceled due to low viability)
3.	Khaosoidown SRS	372	88	1,000	1969
4.	Donglan SRS	408	51	600	1972
5.	Maetha SRS	528	40	0	1974 (later changed to SPA)
6.	Chiang Rai SRS	8	100		1987
7.	Maemy Plantation	7	22	*	1967
8.	Khaokrayang FIO Plantation	9.6	34	*	1967
9.	Thungkwian FIO Plantation	12.8	7	*	1968
10.	Maejang FIO Plantation	8	15	*	1968
11.	Maemoh FIO Plantation	7.68	16	*	1969

Sr.	Name of CSO	Area (ha.)	No. of clone	Seed productivity (Kg/yr)	Established year
12.	KhunMaekummee FIO Plantation	8	12	*	1969
13.	Maehorphra FIO Plantation	17.6	13	*	1971
14.	Maesaikum FIO Plantation	16.8	41	*	1971
15.	Maelee FIO Plantation	14.4	65	*	1972
16.	Ban Danlanhoi FIO Plantation	16	26	*	1974
17.	Maejam FIO Plantation	2.88	26	*	1975
18.	Maelamao FIO Plantation	19.2	16	*	1975
19.	Wangchin FIO Plantation	16	41	*	1977
20.	Maesroi FIO Plantation	16	9	*	1978
21.	Thapla FIO Plantation	12.8	30	*	1978
22.	Thai Plywood Co. Plantation	6.4	25	*	1985

*No seed collection

Breeding orchard

Breeding orchards are established for the creation of new cultivars for offspring selection along with the establishment of a clonal test for re-selection of mother plants. The objectives of breeding orchards are as follows:

1. To be used for random mating within each parent group (sub-populations) and create new breeds of teak in the coming generations.

2. To produce seeds for raising plantations for testing or for breeding control and collecting seeds for testing.

According to the teak breeding strategy of the project, breeding operations are divided into 5 groups or sub-lines of 100 clones each, with a total of 500 clones for breeding purposes. The sub-lines will used to create a breeding orchard. Genetic thinning of seed-breeding orchards is performed twice for 50 % of the existing mates using the results of clonal test and of breed testing through open-pollinated progeny test as shown in Table 21-3.

Table 21-3 Evaluation and genetic thinning plans of teak breeding orchard in each plot (block)

Age (years)	number of clones	number of plants/rai	Area/plant (m^2)	Spacing (approximately) m^2
1	100	32	50	7.1 x 7.1
12	50	16	100	10.0 x 10.0
28	25	8	200	14.1 x 14.1

Genetic thinning at 12 years (50%) was based on the results of a clonal test. Genetic thinning at 28 years (50%) using the results of a progeny test of 50 mothers (clones/families)

Accomplishment in establishment of breeding orchard

Teak breeding orchards were set up in 5 areas in 1988 of which only 4 areas (consisting of six plots) survive today at Ngao SRS, Mae Gar SRS (2 plots), Khao Soi Dao SRS and Dong Lan SRS (2 plots). Planting design for breeding orchards uses a Randomized Complete Block Design (RCB) with each test plot consisting of 100 clones in 6 blocks and in each block planting was done at a spacing of 7 x 7 meters (total 600 plants per garden).

Progeny Test

While selecting Plus trees only externally observable characteristics, or phenotype traits, are used and the genetic value of the tree, and how much of the good traits can be passed on to offspring, are unknown. Assessment of the genetic value of the mother tree can be done through the progeny test. It is a test to compare the offspring of different parents. This test is used backwards for reselection of the mother or parents. Once the best parents are identified forward selection is carried out by choosing the best individuals out of the test. The best individuals are then made available to the farmers for raising clonal plantations. There are two types of the progeny test. One is half-sib, or open progeny test, with pollination occurring due to wind or insects and with only mother side known. The other is full-sib progeny test which pollination is controlled and both of parents are known.

Half-sib progeny test conducted in Thailand.

Results of half-sib progeny trials conducted earlier in Thailand were not very promising primarily due to limited number of plus trees most of which were from the same provenance. Damage to the trees caused by forest fires further made the evaluation impossible.

These limitations were addressed appropriately and half-sib progeny tests were conducted again. Planting material for the test were seeds of 295 families from 180 Plus trees collected from CSOs at Maegar SRS, Donglan SRS and breeding orchard at Ngao SRS. Seeds of the same Plus tree number but collected from different CSOs were considered as different families. In addition, tissue culture plantlets from 3 plus trees, and seedlings from 2 plus trees were also used as planting material for these trials. Planting was done at 4 sites in the beginning, but the Lansang SRS site was discarded subsequently due to poor survival owning to prolonged drought. Only 3 sites at Intakhin SRS in Chiang Mai, Donglan SRS in northeastern, and Bantakhun SRS in southern were left from where experimental data was collected. The evaluation is yet to be completed.

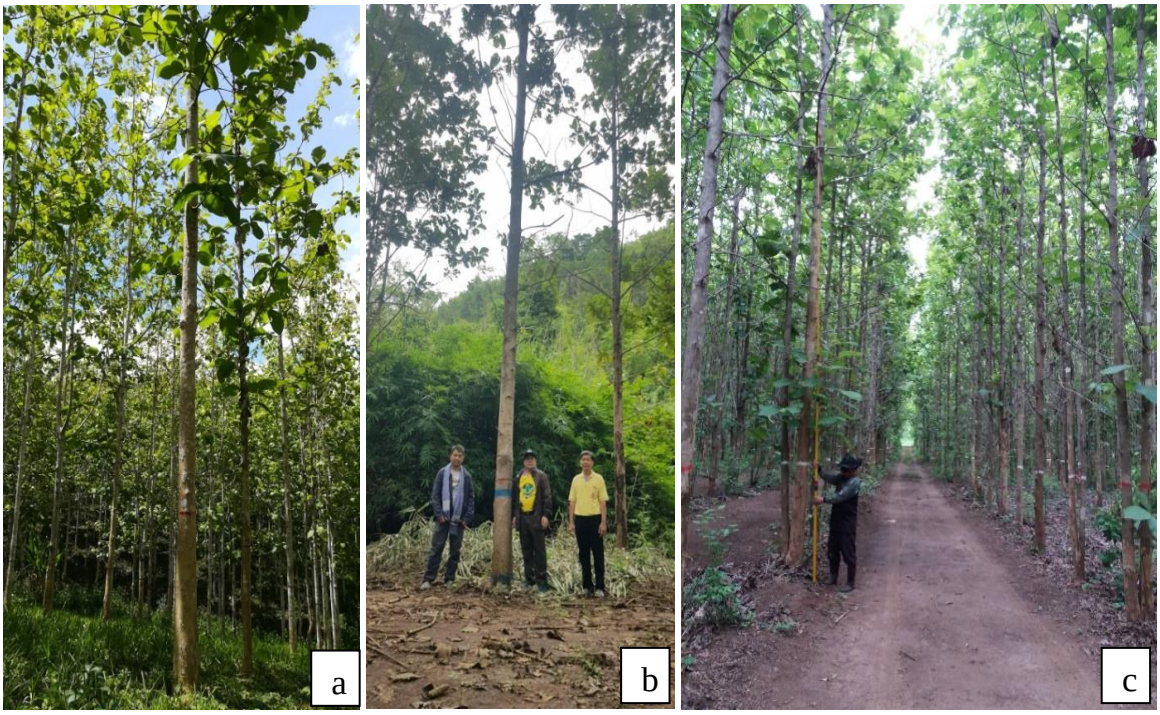

Photo 21-3 Performance of 8 year-old teak trees in half-sib progeny test plots at a) Bantakhun SRS, b) Donglan SRS, and c) Inthakhin SRS

Information and outcome expected from this test are as follows.

Quantitative Inheritance: Population parameters that could be evaluated are Mean, Variance, Standard deviation of the Population, Phenotypic value, and Genetic value.

Heritability: Broad-sense heritability, Genetic gain.

Genetic Combining Ability (GCA): From this value, the genetic worth or breeding value of the mother could be evaluated.

Clonal Planting Materials: Forward selection of individual elite trees from the test plots could be done for promoting clonal plantation.

Seedling Seed Orchard *(SSO).* After all data collection, the testing plots could be converted to SSO.

Full-sib progeny test

Full-sib progeny test is the test which both of parents are known by performing control pollination. The test aims to use characteristic of progeny to evaluate breeding value of their parent. From this test not only Genetic Combining Ability (GCA) and additive genetic variance of the parent but also Specific Combining Ability (SCA) can be calculated. Better parent are the parent with higher ability to transfer desired characteristics to their offspring. The parent will then be selected in further improvement program. At the same time some progenies that perform better than others in the trial could be selected and vegetative propagated for clonal plantation with higher genetic value.

Control pollination -

Control pollination is pollinating the female flowers of a tree with pollen from a known source, usually one specific tree. Usually the flowers are protected from undesirable pollen by covering them with a pollen-tight cloth or paper bag before they are receptive and adding known-source pollen at receptivity.

Full-sib progeny test in Thailand.

Two sets of full-sib progeny were conducted. First set was conducted in 2006 with full diallel mating design of 5x5 pairs with reciprocal. One side parent was of

Lampang origin while the other was from outside Lampang (Chiang Mai and Maehongsorn Provinces). A total of 50 families from controlled crosses and 4 from open pollinated for comparison were planted in 2007 at 4 different sites with contrasting soil and climatic characteristics. The experiment was set up in a randomized complete block design with 4 replications of 3x3 plants each family at spacing 4x4 meter. But only two sites at Phitsanulok SRS, Phitsanulok Province and Dong Lan SRS, Khon Kaen Province could be used to obtain growth data. (Wattanasuksakul et al., 2013). First evaluation was reported at 5 years age and presented at the world teak conference held in Bagkok. It was concluded that growth of progenies was significantly affected by sites and Donglan proved a better site than Phitsanulok. There were significant male and female interaction effects on growth of teak progenies planted at Donglan when Plus trees from Lampang were female. Reciprocal effects occurred in one case at Phitsanulok site. Significant effect on DBH growth of progenies was noticed when Plus trees from outside Lampang were male but none while being female. At 5 year old teak progenies were too young to evaluate their parents in term of heritability, GCA, and SCA (Wattanasuksakul et al., 2013). Backward reselection is now under the process of calculation and evaluation. Improved genetic material has already been made available to the farmers.

The second set was conducted in 2008 with partial diallel mating design of 4x4 pairs of plus trees from Phrae, Mae Hong Sorn, Lampang and Chiang Mai. Trees from the same origin were not mate and only one way crosses were conducted. A total of 12 families were planted in 2010, at 4 different sites with contrasting soil and climatic characteristics, but only 2 sites at Phitsanulok SRS, Phitsanulok Province and Dong Lan SRS, Khon Kaen Province could be obtained data. 3 sets of experiment were set up in a randomized complete block design with 4 replications of 3x3 plants each family at spacing 4x4 meters. The evaluation is yet to be completed.

Lessons Learned and Recommendations

1. Breeding of mother trees regardless of their sources or cross breeding a closely related tree may result in a breed with inferior characteristics. Therefore, before breeding, it is necessary to examine parent's history thoroughly to avoid such problems.

2. For half-sib progeny test when many mother trees are tested, forward selection may be done by thinning bad families and keeping desired families to create second generation seedling seed orchard (SSO). When creating the SSO by this technique, it has to be ensured that no tree of the same family stand next to each other which must be planned in advance when establishing the progeny test.

3. Mother trees with high Genetic Combining Ability can be selected to be mating pairs for conducting full-sib progeny test and finding their Specific Combining Ability.

4. Since improvement program of teak takes a very long time and process cannot finish within one generation, team work of many generations is a key to keep the process running continuously and correctly. This requires a detailed protocol to be established for passing on information and experiences from one batch of researchers to the next.

5. There are many testing plots such as clonal tests planted in 2001, 2003 and 2006, half-sib progeny test, and full-sib progeny tests had been established and well maintained but have not yet evaluated and utilized. Reports on these trials should be done as soon as possible and benefits by way of improved planting stock made available to the farmers at the earliest.

6. Results from these ongoing trials should be used to establish protocols for genetic

thinning in the seed orchards to further improve the quality of seed sources.

7. It would be best to start the tests with at least 4 testing sites to evaluate genetic and environment interaction effects because in long term research work like this it is not unusual to lose some testing sites to factors beyond the control of the Forest Department.

Conclusion

In this teak improvement program set up almost six decades back in1965 as many as 636 Plus trees were selected throughout the forests where the resource is distributed and a total of 509 clones of plus trees have been planted in clone banks at five sites. Three sets of clonal test of almost 500 clones have been conducted at various sites during this period and both half-sib and full-sib progeny tests have been conducted. But several of these tests have not yet been evaluated and utilized for further use. This requires immediate action so that the full benefit of the teak improvement program may become available to all stakeholders at the earliest.

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