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Comparative Study on Root Development of Teak (*Tectona grandis* L.f.) for Different Propagation Methods (Tissue Culture, Rooted Cutting, Seedling) at Different Stages

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အပင်မျိုးပွားခြင်း နည်းစနစ်အမျိုးမျိုး(တစ်ရှူးမွေးမြူခြင်း၊ အညွှန့်ကိုင်းထိုးခြင်း၊ အစေ့မှ ပျိုးထောင်ခြင်း) မှရရှိသော ကျွန်းပင်များ၏ အမြစ် ကြီးထွားမှုများအား နှိုင်းယှဉ်လေ့လာခြင်း

ဦးအုန်းလွင် (လက်ထောက်ညွှန်ကြားရေးမှူး၊ သစ်တောသုတေသနဌာန)

စာတမ်းအကျဉ်း

ဤစာတမ်းတွင် ကျွန်းတစ်ရှူးမွေးမြူခြင်း(Tissue culture)၊ အညွှန့်ကိုင်းထိုးခြင်း(Shoot cutting) နှင့် သစ်စေ့မှမွေးမြူခြင်း(Seedling) နည်းဖြင့် ရရှိသော ကျွန်းပင်များ၏ ပျိုးဥယျာဉ်အဆင့် နှင့် ၄-နှစ်မှ ၆-နှစ် သားရှိ စိုက်ခင်းအတွင်း အမြစ်ကြီးထွားမှုများကို နှိုင်းယှဉ် လေ့လာတင်ပြ ထားပါသည်။

ကျွန်းတစ်ရှူး မွေးမြူရာတွင် အပင်အစိတ်အပိုင်း (Explant) ၃-မျိုး အသုံးပြု ခဲ့ပါသည်။ ၄င်းတို့မှာ ရွေးချယ်ထားသည့် ကျွန်းပင်၏ ထိပ်ဖူးကြားဖူး (Terminal and lateral bud of selected teak plus tree)၊ ရောဂါကင်းသော အခြေအနေတွင် သစ်စေ့မှအညောင့် ပေါက်လာသော အပင်၏ အဆစ်ပိုင်းများ (Mono-nodal segment of *in vitro* sterilized seed)၊ ပျိုးဥယျာဉ်ရှိ ပျိုးအိတ်အတွင်း ပျိုးထောင် ထားသော ကျွန်းပင်၏ အညွှန့်ထိပ်ပိုင်း (Shoot-tip) တို့မှ စမ်းသပ် မွေးမြူခဲ့ပြီး အဆိုပါ နည်းစနစ် ၃-မျိုး၏ရလဒ်များကို နှိုင်းယှဉ် ဖော်ပြထားပါသည်။ စမ်းသပ်ထားသော ကာလအတွင်း အဖူးမှ မွေးမြူထားသော ကျွန်းတစ်ရှူးပင်သည် အခြားသော အပင်အစိတ်အပိုင်းများ မွေးမြူခြင်း ထက် အမြင့်ကြီးထွားမှု ပိုမိုကောင်းမွန်ကြောင်း တွေ့ရှိရပါသည်။ တစ်ရှူးမွေးမြူခြင်းမှ ရရှိသော အညွှန့်များအား အမြစ်ထွက်ခြင်း(Rooting)စမ်းသပ်ရာတွင် ပိုးသတ်ထားသော သဲအတွင်း ဆောင်ရွက် ပါက ပိုမိုအကြမ်းခံပြီး ကုန်ကျစရိတ် သက်သာကာ အပင်ကူးပြောင်းရာတွင်လည်း အောင်မြင်မှုပိုမို ကောင်းကြောင်း တွေ့ရပါသည်။

ပျိုးဥယျာဉ်အဆင့် စမ်းသပ်ခြင်းတွင် သာမန်သစ်စေ့မှ ရသောအပင် (Seedling)၊ အညွှန့်ကိုင်းထိုး အမြစ်ထွက်ပင် (Rooted cutting)များ၏ အမြစ်ကြီးထွားမှု(Root development)များကို နှိုင်းယှဉ်လေ့လာရာ ပျိုးအိတ်ငယ်(၇"x၃"x$\frac{2}{4}$")အတွင်း ကွဲပြားခြားနားမှုကိုတွေ့ရှိရသော်လည်း တစ်ရှူးပင်နှင့် အညွှန့် ကိုင်းထိုးပင်များမှာမူ ကွဲပြားခြားနားမှုမရှိကြောင်း တွေ့ရှိရပါသည်။ ပျိုးအိတ်ကြီးအတွင်း အမြစ်ကြီးထွားမှု အခြေအနေများမှာမူ နည်းစနစ် အားလုံး မှရရှိသော အပင်အားလုံး သိသာစွာ ကွဲပြားခြားနားမှု မရှိကြောင်း တွေ့ရှိရပါသည်။

ယခုအခါ မြေချိုက်ပျိုးထားသော ၄-နှစ်၊ ၅-နှစ် နှင့် ၆-နှစ်သားအရွယ်ကျွန်းတစ်ရှူးပင်များ နှင့် အသက်ရွယ်တူအစေ့ပေါက် ကျွန်းပင်များ၏ မြေပေါ်မြေအောက် ကြီးထွားမှု အခြေအနေများကို ပဏာမလေ့လာဆန်းစစ်ရာ အမြင့်ကြီးထွားမှု(Height growth)တွင် အဖူးမှ မွေးသော ကျွန်းတစ်ရှူးပင်သည် အကောင်းဆုံးဖြစ်ကြောင်းတွေ့ရှိရပါသည်။(၄)နှစ်သားအရွယ် စမ်းသပ်ချက် တွင်မူ အပင်များ အားလုံး အမြင့်ကြီးထွားမှု ကွဲပြားခြားနားမှု မရှိကြောင်း တွေ့ရှိရပါသည်။ ရွက်အုပ်ကြီးထွားမှု(Crown diameter)သည် အမြစ် ဘေးသို့ ဖြာထွက်ခြင်း(Root-spread)နှင့် ပင်စည်လုံးပတ် ကြီးထွားမှု(DBH) တို့နှင့်အပြန်အလှန်ဆက်စပ်မှု ရှိကြောင်း တွေ့ရှိရပါသည်။ အမြစ်အရေအတွက် (Root-quantity)သည် အသက်အရွယ်ကွဲခြားမှု(Ages)၊ အပင်အမြင့်ကြီးထွားမှု (height growth)အပြင် အခြားသော အမြစ် ဘေးသို့ဖြာထွက်ခြင်း (Root-spread) လက္ခဏာများနှင့်ပင် ဆက်စပ်မှု မရှိကြောင်း စမ်းသပ် တွေ့ရှိရပါသည်။ နိဂုံးချုပ်အားဖြင့် ကျွန်းပင်၏ အမြစ်ကြီးထွားမှု (root-development) သည် ပျိုးအိတ်ငယ် အဆင့်မှလွဲ၍ အပင်မျိုးပွားခြင်းနည်းစနစ် အသီးသီးတွင် ကွဲပြားခြားနားမှု မရှိကြောင်း စမ်းသပ် တွေ့ရှိရသည်များကို တင်ပြထားပါသည်။

Comparative study on root development of teak (*Tectona grandis* L.f.) for different propagation methods (tissue culture, rooted cutting, seedling) at different stages

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Abstract

In this study, variation of root development of teak from different propagation methods such as tissue culture, shoot-cutting, and seedling by conventional way, different origins of explant for tissue culture method and different stages at tissue cultural lab, nursery and field were investigated. Study-area I for tissue culture experiment, 'bud' (terminal and lateral) from mature teak-plus-tree, 'nodal segment of sterile seed' collected from different seed sources, and 'shoot-tip' from seedling grown in nursery were mainly used as explants for tissue culture. The 'bud' was found to be the best than other sources of explants. Rooting in sterilized sand box showed the best for survival, hardy and cost effective than rooting in culture media. For study-area II in nursery experiment, variation of root development found out only in small-bag (7"x3"x ¾") but the similar root development was observed between tissue cultured-plant and rooted shoot-cutting. Teak plants grown in big-bag (12"x8") were found no significant differences of root performance among all plant propagation methods. For study-area III in the field, the study found out that significant difference was only remarkable in height growth influenced by the origin of plant. Tissue cultured-teak was found to be the best in height growth in this study. Growth rate of teak trees in the field were no significant difference up to 4 year old while there is no site effect. The study proposed that there was an initial establishment growth-stage for tested origins and propagation methods up to 4 year-old in this study. Moreover, the result revealed that the morphological characteristics of crown diameter and 'root-spread' were positively associated with the growth of DBH. This study found out that there was no correlation between number of root and any other root performances such as root-spread and root-depth. Moreover the result indicated that root-depth (vertical development) was not so important factor affecting height growth within tested ages.

Finally, this study concluded that root development of teak in all stages except in small bag was found no significant differences between conventional seedling and vegetatively rooted teak.

***Key Words**: crown diameter, explant, growth, morphological characteristic, plant propagation, root development, shoot-cutting, teak, tissue culture.*

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Comparative study on root development of teak (*Tectona grandis* L.f.) for different propagation methods (tissue culture, rooted cutting, seedling) at different stages

1. Introduction

Nowadays, strong international timber demand for good quality teak (*Tectona grandis* L.f.) has accelerated in depletion of natural stocks which are increasingly protected by strict conservation policies to preserve biodiversity. This situation has resulted in changes in the basic plantation concept of teak. Traditional teak plantations, managed mostly by state organizations for harvesting in 60–80 years (Ball *et al.* 2000), are no longer well-adapted to the current needs of private investors looking for the best returns in the shortest possible time. For such investors, the quality and the source of teak planting stock and propagation method have become a crucial issue (Monteuuis, O. and H-F. Maître, 2007).

Among other planting stock production, tissue culture has become one of the popular method to multiply good mother tree or candidate plus-tree for the impressive development of plantation forestry in tropical countries. Planting materials need not only be of adequate supply but also to be high quality. In this context, tissue culture together with vegetative propagation methods is an important solution to develop plantation forestry. In Myanmar, tissue culture technique for teak has been jointly accomplished by Forest Research Institute, FRI and the Central Forestry Development Training Centre, CFDTC under the management of Forest Department, Ministry of Forestry in 2001. In July 2002, the first batch of tissue-cultured teak has been successfully released from the nursery to the field. More than two thousands of tissue-cultured teak stocks were planted in different places in 2003. It is therefore said to be right time to report somewhat their growth performance in the field even at young stage. However, this achievement is still at the experimental stage, it is an indication of high potential for further progress of plantation forestry in Myanmar (Myanmar Forestry Journal, 2003)

On the other hand, production of planting stock by rooted shoot-cutting from Teak Hedge Garden (THG) has been successfully introduced with the purpose of practicability and cost effective to compare tissue technique.

Therefore selection of appropriate teak propagation method and their comparative growth performances are needed for the development of plantation forestry in Myanmar.

2. Rationales

The conventional means of teak propagation is through the use of seeds and its stumps. However, seed source is limited by availability and poor germination percent and further, by variability in the growth and performances (God D.K., *et al,* 2000).

Normally, the traditional means of propagating teak through seeds has been practiced for centuries. While it allows the possibility of storing seedlings in the form of 'stumps' for transportation, to wait for suitable planting conditions, etc., this mode of sexual propagation has the following serious handicaps:

(i) the quantity of seeds produced per tree is too limited and their germination rates remain low overall (20– 25%);

(ii) the period to reach the flowering/seed-bearing stage is lengthy.

(iii) significant variability of economically important traits (growth, form, wood technological and aesthetic characteristics, etc.) among individuals even when derived from the same mother tree ; and

(iv) limited knowledge about the inheritability of such economically important traits and consequent uncertainty about potential gains from costly breeding programs (Monteuuis, O. and H-F. Maître, 2007).

Several experts (e.g. Kjaer and Foster 1996, Kjaer et al. 2000) have documented these shortcomings. White and Gavinlertvatana (1999) stated that the 'seedling route' is outdated and actually represents a deterrent to wide scale increased productivity in teak plantations, and as such to commercial teak plantation investment. According to these authors, the magnitude of the real genetic gain associated with the seedling route remains uncertain, as does the value of teak breeding efforts employing it over the past several decades. This is undoubtedly a major concern for potential investors, for whom rapid and assured returns are crucial (Monteuuis, O. and H-F. Maître, 2007).

Considering the importance of producing good planting stock for teak plantation program and being lack of technical information in clonal propagation methods in Myanmar, it is expected that a further study to fill up the gap of this particular point is undoubtedly necessary nowadays.

Therefore, the selection of appropriate method for planting stock production with outstanding growth performance is urgently needed for the development of plantation program in Myanmar.

3. Objectives

In order to explain more detail information on growth of teak for different propagation methods regarding to their root development, this study was laid down with the following objectives.

(1) To observe root development of teak planting stock for different propagation methods at different stages,

(2) To comparatively study the growth performances of tissue-cultured teak and normal teak tree in the field,

(3) To investigate relationship among measurable morphological characteristics and

(4) To carry on tissue culture experiment as the follow up activities of previous teak tissue culture project (2001-2002).

4. Literature Review

Relevant literatures were cited to support the results of this study.

Tissue culture

The advantages to be gained by using plant tissue culture techniques are (i) the increased rate of multiplication supersede conventional vegetative propagation methods and (ii) in crops where vegetative propagation is either difficult or impossible by conventional means, tissue culture has a clear advantage, (iii) disease free plants can be produced, and (iv) international transfer of plant is acceptable without quarantine.

The disadvantages are (i) cost and overheads in maintaining a tissue culture laboratory are considerably higher when compared to maintaining facilities for

conventional methods of propagation, and (ii) during rapid scaling-up processes, the occurrence of somaclonal variations and genotypically deformed plants may occur if care is not taken at all stages of production (K. Harikrishna *et al*, 2002) and (Sato T, 1995).

Investigators from Thailand studied teak tissue culture and reported essential findings as follows;

1) Teak can be propagated successfully by using the tissue culture (the shoot-tip and nodal segment culture) technique.
2) The rate of shootlet multiplication from a single shoot is about 2-3 shoots/sulture/45 days and or 8 folds in 45-60 days after sub-culturing.
3) The shootlets can be easily rooted under the mist conditions.
4) There is no different between the nursery grown seedlings and the transplanted plants in their shoot/root system (Kaosa-ard, A *et al.,* 1987, 1988).

Since 1979, Perum Perhutani in Indonesia has cooperated with the Bandung Institute of Technology on teak tissue culture research (Wirjodarmodjo and Subroto, 1983). Noerhadi and Wirjodarmodjo (1980) reported research results on teak tissue culture as follows:

1) Callus growth from stem and petiole gave a predominant type response. The explant after 3 weeks, and treatment with BAP hormone, was planted in a modification of JS and MS medium; hormone 2 4-D in concentration up to 3.5 ppm produced a better and larger callus compared with NAA hormone with concentration up to 10 ppm.

2) A cut young leaf and pedicel also produced callus, but at a very low rate and not consistently, compared with callus from stem and leaf stalk.

3) Root formation from the explant is noted after 2 months planting in the same medium, with additional NAA and BAP hormones of concentration 3.5 ppm and 0.25 ppm respectively.

Gina H. M and W.E. Vidaver (1988) studied on micropropagated conifer with emphasis on their effects on root quality and plantlet performance in the nursery and field and reported that major influences on root production include auxin concentration and mode of application, shoot (explant) quality, donor age, clone and temperature. They stated that further development of the root system may be enhanced by early air-pruning and ectomycorrhizal association.

Three years after out-planting of tissue cultured teak, there is no difference in morpho/phenological development between trees planted from seedlings and from tissue culture plants (Kaosa-ard, A *et al.,* 1987, 1988).

P.K. Gupta studied clonal multiplication of teak by tissue culture in 1980 and reported similar findings that their growth and root system, with a tap root and laterals, were similar to those of plants raised from seeds.

God D.K., *et al*, 2000 reported that the using a sole multiplication/ elongation culture medium with minimal hormone addition, an exponential multiplication rate of 3 to 4 microcutting per plantlet can be obtained at every six to eight week cycle.

Pramod K. Gupta, Roger Timmis and A. F. Mascarenhas, 1991 reported that field performance of micropropagated forestry species compare to seedling was found no morphologic variation was observed in microprogated plants.

Vegetative Propagation

Since the mid-1990s, millions of rooted cuttings and micro-cuttings of clonally propagated teak trees have been produced and planted by private companies all around the world. The superiority of such planting material compared to seedlings has led to increasing interest in this technology from both private investors and landowners eager to maximize returns in a reasonable time (Monteuuis, O. and H-F. Maître, 2007).

In contrast to seed propagation (where every individual in genetically different from every other), asexual or vegetative propagation involves duplicating (theoretically without limit) genotype while preserving through mitotic divisions their original genetic-make-up, and consequently their individual characteristics. Moreover vegetative propagation is applicable to any individual, even those without fertile seeds, due to immaturity, unfavourable environmental conditions, or other factors (Monteuuis, O. and H-F. Maître, 2007). They mentioned that more practically, propagating teak vegetatively by cuttings can be useful for establishing 'safe' clonal seed orchards, avoiding risks of 'illegitimate' clones associated with clonal seed orchards traditionally produced by grafting on unselected stock. Clonal propagation by rooted cutting from wisely selected teak 'plus' trees remains the only way to generate top grade teak timber trees in a reasonable time, counteracting the heterogeneity associated with seedling or even bulk options.

A number of researchers informed on clonal propagation of forest trees and its benefits in plantation forestry as follows.

Karnosky, D.F, 1981 reported that mass propagation by cloning-selected superior genotypes for planting stock captures both additive and non-additive gene effects; thus, a significantly higher genetic gain in anticipated than from traditional methods (Rediske 1978). At least a 10% increase can be expected from planting selected clonal propagules rather than selected half-sib families (Kleinschmit 1974).

In general, the more the number of root fiber system the greater the uptake of nutrients consequently result the growth of the plant. McKeand, S.E, 1983 reported that the main differences between plantlets (tissue or shoot-cutting) and seedlings were related to root system morphology rather than physiological processes for conifer species.

Cuttings are hard to root and when do, generally form a fibrous rather than tap rooted system produced from seed. Such trees may prove not to be wind firm (Saw C. Doo, 1983). He studied on vegetative propagation of teak (*Tectona grandis* L.f) by branch cutting in 2001 and reported that the growth response of teak branch cuttings and teak seedlings outplanted in the field shown no significant difference in growth.

5. Materials and Methods

This study was appropriately conducted at CFDTC, *Hmawbi* where tissue culture lab, nursery and glasshouse, tissue-cultured-teak plantation and teak provenances-collection plantation are located in addition to capacities available there. There was no teak plantation established by using rooted-cutting in *Hmawbi*. Overall experiment setting up for the study was shown in table1.

Table 1. Experiments for study area

Propagation method	Origin of plant	Abbre-viation	Study area		
			I. *In vitro*	II. Nursery	III. Field
1. Tissue culture	Bud	Bd	✓	✓	✓
	Sterilized seed	Sd	✓	✓	✓
	Shoot-tip	Sh	✓	✓	✓
2. Conventional	Seedling	Slg	×	✓	✓
3. Vegetative	Shoot cutting	Sc	×	✓	×

✓= studied × = not study

The whole experiment was therefore assembling with three study areas as follows.

(i) Study-area I (Growth *in vitro* at tissue culture lab)

(ii) Study-area II (Growth in nursery) and

(iii) Study-area III (Growth in the field)

Among above stated three study areas, 'study-area I (growth *in vitro*)' and 'study-area II (growth in nursery)' were done with simple – descriptive method based on previous experience from watchful observation throughout the teak tissue culture project in 2001 to 2002 and currently data collection. On the other hand, 'study-area III (growth in the field)' condition was systematically investigated by using unbalanced design and statistical analysis.

5.1 Study-area I (Growth i*n vitro* at tissue culture lab)

In tissue culture experiment, 'bud (terminal and lateral)' from mature teak-plus-tree, 'shoot-tip' from seedling grown in nursery, 'nodal segment of sterilized seed' collected from different sources were mainly used as explants for tissue culture micro-propagation techniques. During tissue culture project (2001-2002), the results of shoot and root development explained in this paper were descriptively compared for each culture-method.

5.2 Study-area II (Growth in nursery)

After rooting stage of tissue-cultured shootlets and shoot-cuttings in glass house, those were transferred into polyethylene bag in nursery. Their variations of root formation were comparatively studied for different propagation methods.

5.2.1 Design and Layout of the experiment for Study-area II (growth in Nursery)

The study on root performance of teak plants in polyethylene bags was done by using simple random design. Studying on 'growth in nursery' referred as development of root performance under this category. Three teak plants with similar age were randomly chosen from two sizes of poly-bag (small size of 7"x3"x ¾" and big size of 12"x8") and each propagation method. An experiment for this study was set up a total of 33 teak plants as shown in table 2.

Table 2. A simple experimental design for studying root development in nursery

Method of propagation	Sources	Number of plants	
		Small-bag	Big-bag
1. Tissue culture	Bud (Bd)	3	3
	Sterilized seed (Sd)	3	3
	Shoot-tip (Sh)	3	3
2. Shooting cutting	Shoot from (THG)	3	3
3. Seedling	Seed	3	3
4. Stump	Seed	-	3
Sub total		15	18
Grand total number of teak sample plants			33

THG = Teak Hedge Garden

5.2.2 Measurement by counting and rating

Based on size of roots, three types were identified such as main, medium-size and adventitious roots in the nurseries of CFDTC and FRI (figure 1). The formation of adventitious root in poly bags was simply graded into three such as few (F), normal (N) and many (M). Counting the medium-size-root performing bigger than adventitious root, and main root of biggest size was done in this study. Detail measurement of tested sample was given in appendix 1.

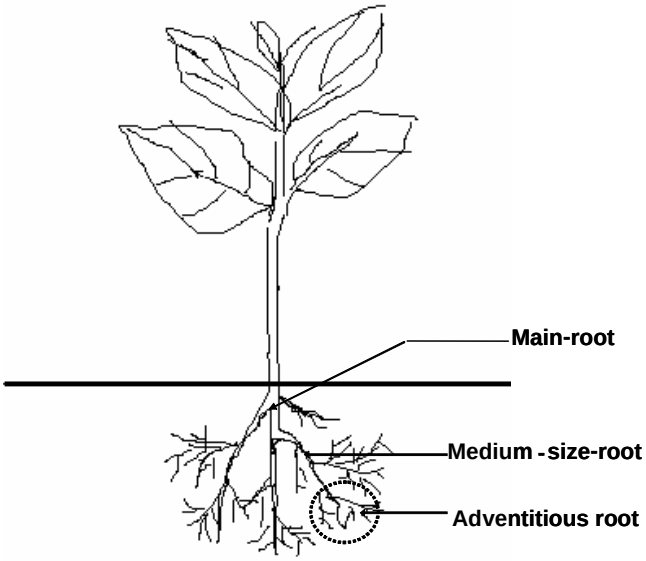


Figure 1. Showing three types of roots investigated in study-area II (growth in nursery)

More clear observations were shown in photographic illustration in later chapter of results and discussion.

5.2.3 Descriptive Analysis

As stated earlier, study-area II of 'growth in nursery' was descriptively studied due to the limitation of the time available, and sample.

5.3 Study-area III (Growth in the field)

Tissue-cultured teaks were firstly planted in July 2002 at the departmental compounds under the Ministry of Forestry for the purpose of memorial event. A batch of those was only planted in 2003, 2004 and 2006 at CFDTC campus and its training forest with simple block arrangement. Their growth and morphological characteristics together with those from teak provenance-collection plantation at the same age were systematically studied at 6, 5 and 4 year old.

5.3.1. Design and Layout of the experiment for 'growth in the field'

Due to availability of tissue-cultured teak in the field sites, experimental design was not enable to make even design with same replication. While origins of plant were formed into group as a treatment, planting sites and ages were found heterogeneity. Likewise, planting sites and age-classes were separately organized into same treatment, the rests consisted unequal sample size. Blocking on origin of plant unequally and their different ages were unequally formed. Therefore, this experimental design was altogether made of 33 teak trees as shown in figure 2 and table 3.

Amongst all treatments, the source of plant was assumed as a main interest in this study.

Tissue-cultured teak trees planted near the laboratory in 2006, training forest in 2004, and near the orchid house of CFDTC campus in 2005 were described in this study as site 1, site 2 and site 3 respectively. The 6 year-old, 5 year-old and 4 year-old teak plantation were given the name as 'Age-6', 'Age-5' and 'Age-4' respectively.

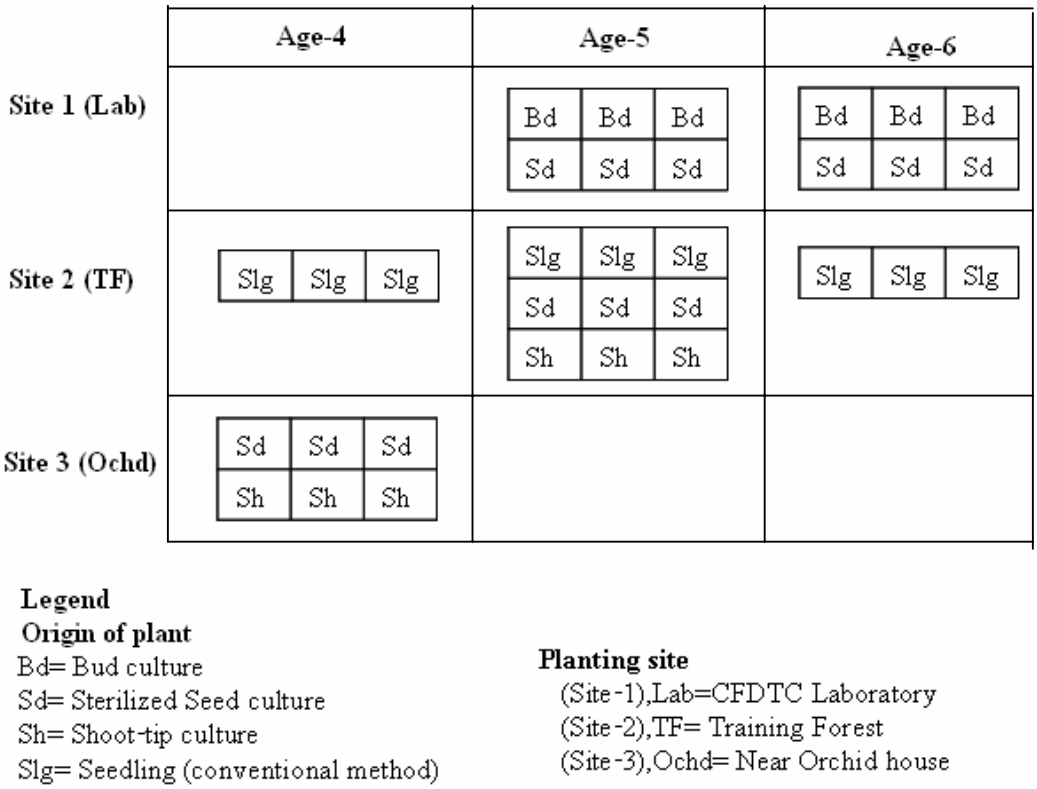


Figure 2. Design and layout of the experiment for growth in the field

Table 3. Frequency of the samples in experiment for study-area III of growth in the field

Propagation method	Origin of plant	Age-6	Age-5	Age-4
1.Tissue culture	Bud	3 (site-1)	3 (site-1)	×
	Shoot-tip	×	3 (site-2)	3 (site-3)
	Sd (Seed)	3 (site-1)	6 (site-2)	3 (site-3)
2.Conventional	Slg (Seedling)	3 (site-2)	3 (site-2)	3 (site-2)
	Total	9	15	9

5.3.2. Measurements for 'growth in the field'

The inner three trees were randomly selected from different origins, ages and planting sites for measurements. Trees growing at border line were excluded in this study with the purpose of avoiding edge effect. All selected teak trees were measured for height, diameter at breast height (DBH) and diameter at the base of root collar too. Based on height and DBH, stem volume index was calculated in order to summarize the growth of measured trees. In addition, each tree was assessed for a number of morphological characteristics such as crown diameter, number of main roots which size was bigger than the diameter of 2.54 cm at 1 meter distance from the base, average diameter of root spreading from the base, and root-depth. Beside, root volume index was also calculated by using root length up to diameter of 2.54 cm and its diameter at mid-length in order to detect relationship with other morphological characteristics. Appearance of adventitious root was excluded in this study. Detail measurements on each sample were shown in table 4 and figure 3. With the help of CFDTC staff, data collection was done in July to September 2009 during the raining season.

Detailed measurements of samples were shown in appendix 2.

Table 4. Measurements on tested characteristics of teak tree growing in the field

Morphological characteristics	Unit	Description
1. Height	m	Total height of the tree
2. Diameter	cm	(i) Measured at 1.3 m above ground (ii) Measured at the base
3. Volume* index	(m^3)	[πr^2 x ht x 0.5 (form factor)] To estimate total growth
4. Crown diameter	m	Average length of two cross-sections of the crown
5. Root-quantity	#	Number of main root which is bigger than 2.54 cm of diameter at 1 meter distance from the base
6. Root spread	m	Average diameter of horizontal radial root spreading
7. Root Volume* index	(cm^3)	[πr^2 x length] To estimate root growth of each tree

(*) indicates that calculation based on data measured

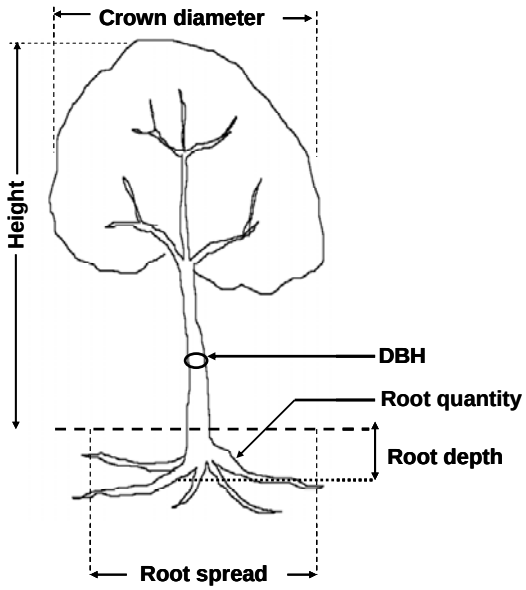


Figure 3. Measurements on tested characteristics of teak growing in the field.

5.3.3. Statistical analysis

Regarding to available design of unbalanced treatment structure for growth in the field, accumulated two-way analysis of variance was only used for overall assessment.

Within the origins, and ages, one-way analysis of variance was practiced to determine the variation of growth, and morphological characteristics. According to unequal design and layout of the experiment, prediction from regression model was chosen to estimate the value of the missing samples for further recommendations.

Based on least significant difference, LSD duncan's multiple-range test (DMRT) was applied to rank the performances of tested origins within the ages.

Moreover, Pearson's correlation coefficient (r) was also used to access the relationship among all tested morphological characteristics.

M.S Excel, 2003, GenStat 9.2 version (PC/Windows XP), Lawes Agricultural Trust (Rothamsted Experimental Station), and SPSS 14.0 Student version were appropriately exercised in this study.

6. Results and Discussion

Result and discussion of this study were divided into three study-areas as mentioned earlier under materials and methods.

6.1. Study-area I (Growth *in vitro* at tissue culture lab)

With the aim of tissue culture techniques to be successful in Forest Department, teak tissue culture project has been purposefully reinitiated in 2001. All data and achievements under the study-area I of 'growth *in virto* at tissue culture lab' were taken from the previous teak tissue culture project of 2001-2002.

Based on three major sources of explants in tissue culture techniques such as (i) terminal and lateral buds of mature teak-plus-tree, (ii) nodal segment of sterilized seedling, and (iii) shoot-tip of young teak seedling at the nursery, three different culture techniques

were accordingly experimented for teak tissue culture project in 2001-2002. Photographic illustration of tissue culture process was shown in figure 4.

Findings of previous experiment were not documented on any technical paper in Myanmar yet. Under this study-area I, some of those major achievements mention for each culture method. However no proper statistical designs were used due to urgency of tissue culture techniques to be successful in those days, a number of remarkable findings produced from comparative analysis was therefore used in this study. Detail explanation of culture-media used in tissue culture won't be mentioned in this paper. Shoot development, shoot multiplication rate per equal cycle, and callus formation would be mainly explained. For root formation, it was tested with several kinds of media consisting different concentration of rooting hormone. Dipping shootlets in root hormone (100 ppm and 200 ppm of IAA, IBA, NAA for 3 to 5 minutes and placing in sterilized sand was finally the best method for the cost effective and more hardy than those rooting in culture media. The acclimatization stage after rooting was equally treated in glass house for all culture methods.

Overall work done for the teak tissue culture project (2001-2002) was summarized in appendix 3.

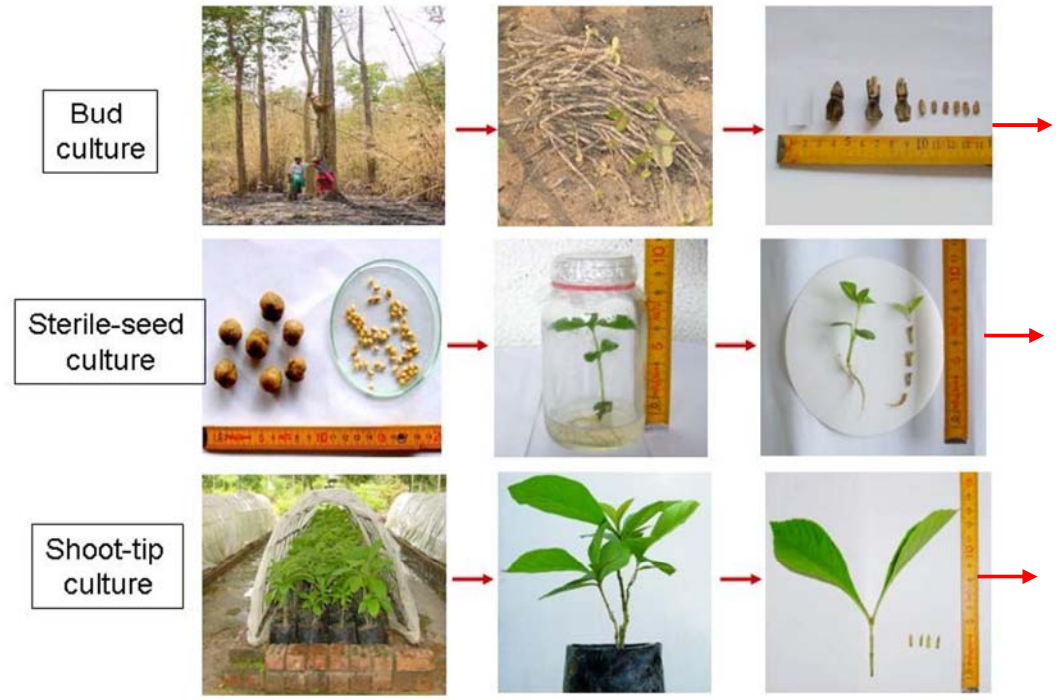
6.1.1. Bud culture

Teak branch-tops (propagule) were collected from 5 provenances in flesh season. The fleshy terminal and lateral buds were taken and used as explant for bud tissue culture. In general, buds collected in March and April compared to the rest of the season were found to be the best for successful induction culture stage. For the multiplication rate, 1.4 times for 45 days cycle was detected. Abstract of the results for bud culture was shown in table 5.

Table 5. Abstract of the results for bud culture

No.	Description	Result
1.	Provenances	5 provenances collected
2.	Season for induction	March and April observed to be the best
3.	Multiplication rate	1.4 times/ cycle(45 days)
4.	Rooting	sterilized sand (IBA, NAA)

IBA=3-Indolebutyric acid, NAA= Naph-thylene-acetic-acid



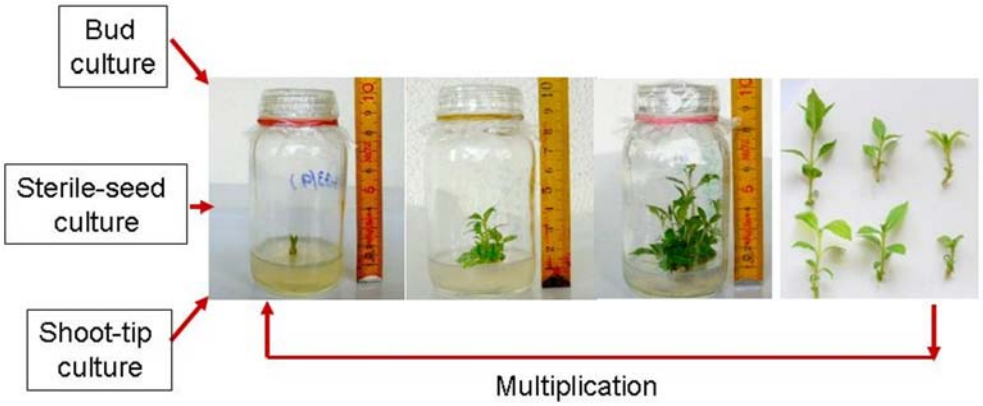


Figure 4. Basic process of bud, sterilized seed and shoot-tip tissue culture

6.1.2. Sterilized seed culture

Seeds were collected from 8 provenances; *Pyay, Aung-lan, Taung-dwin-gyi, Oh-bauk, Bago, Kywe-shin, Myint-kyi-na, Let-pan-kon* clonal seed orchard and *Than-daung*. Two provenances from *Pyay* and *Bago* revealed superior for seed germination in aseptic condition. The season for best germination exhibited 91percent in August followed by 80 percent in July and gradually decreased by 75.28 percent in June, 58.5 percent in May, 39.47 percent in April and a little higher with 62.5 percent in March. The season for poor germination was found throughout the winter season from November to February.

For seed germination test, 16 different kinds of media including water agar were tested in aseptic condition but there was observed not much different results among them. Based on experiences and cost effective point of view, water agar (agar with sugar) revealed good for seed germination. For multiplication test, the best rate was observed at 3.8 times per cycle of 45 days with the average of 2.6 times. A total of 7 different media were used in multiplication experiment. Summary of the result of sterilized seed culture was presented in table 6.

Table 6. Abstract of Results for sterilized seed culture

No.	Description	Result
1.	Provenances	2 of 8 provenances were observed best for germination
2.	Germination % accompanying with season	91%(August), 80% (July), 75.28%(June), 58.5%(may), 39.47%(April)and 62.5(march) Poor germination from November to February
3.	Germination media	Agar with sugar
4.	Germination period	7 days to 45 days (75% was found between 7-10 days)
5.	Multiplication media	2 of 7 media found to be the best
6.	Multiplication rate	3.8 times/45 days-cycle with 2.6 times in average
7.	Callus formation	10 to 55% in different media
8.	Rooting	Sterilized sand (IBA, IAA)

IAA- 3-Indoleacetic acid

6.1.3. Shoot-tip culture

Shoot-tips were collected from the young teak seedling grown in nursery of CFDTC and used as an explant for shoot-tip culture. Identification of seed source for seedling was impossible due to time limitation of teak tissue culture project to be success urgently. In shoot-tip culture, as many as 37 different kinds of media were used but only 6 of those revealed to be the best. For multiplication test, 1.5 times for 45-days-cycle was observed in this culture. Callus formation was rarely found in shoot-tip culture compared to others culture. Abstract of the results for shoot-tip culture was stated in table 7.

Table 7. Abstract of the results for shoot-tip culture

No.	Description	Results
1.	Collection	From seedling (unknown-origin) grown in the nursery
2.	Multiplication media	6 of 37 different kinds of media found the better
3.	Multiplication rate	1.5 times/45 days-cycle
4.	Callus formation	rarely found
5.	Rooting	sterilized sand (IBA)

6.2. Study-area II (Growth in nursery)

In the nursery, teak rooted planting stocks obtained from all propagation methods were investigated on variation of root morphological characteristics in two different sizes of poly bag (small bag 7"x3"x ¾" and big bag with 12"x8") for different sources. A total of 33 teak planting stocks were examined by counting main root and medium-size-root (lateral root) and rating adventitious roots.

Based on observation of mathematical mean value of root performance in small bag, shoot-tip (Sh) of tissue culture performed the best in number of main roots while rooted shoot-cutting was superior in number of medium-size-root and adventitious root too. The seedling was exceptionally found to be the poorest in adventitious root.

On the other hand, their mean value of root performances in big bag, bud (Bd) and shoot-tip (Sh) of tissue cultured teak and the stump were superior together in number of main roots. While the rooted shoot-cutting was observed the best in number of medium-size roots, sterilized seed tissue culture and stump were the best in performance of adventitious root in big-bag.

Root appearances of tissue cultured-teak, rooted shoot-cutting, and seedling and stump in small bags and big bag were exhibited in figure 5 and 6 respectively.

The result of root development of teak planting stock in nursery was shown in appendix 1.

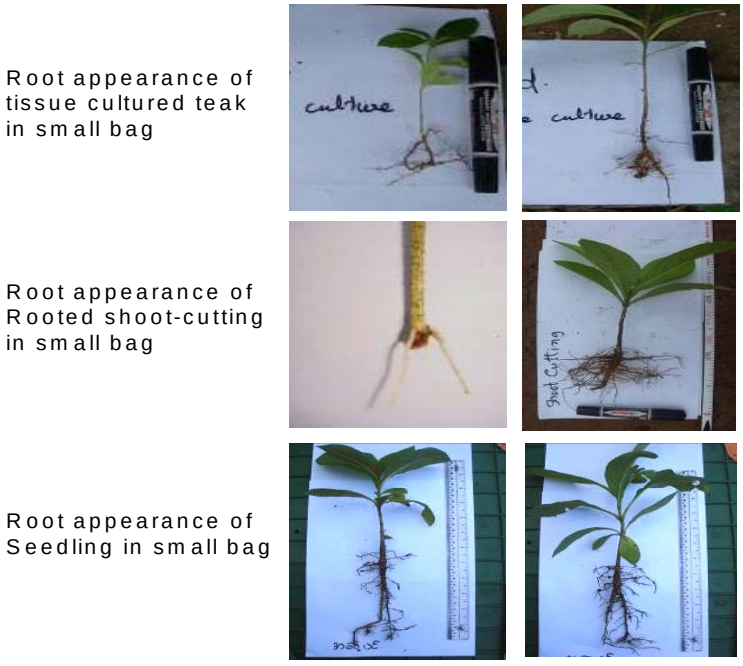


Figure 5. Root appearances of tissue cultured-teak, rooted shoot-cutting, and seedling and stump in small bags

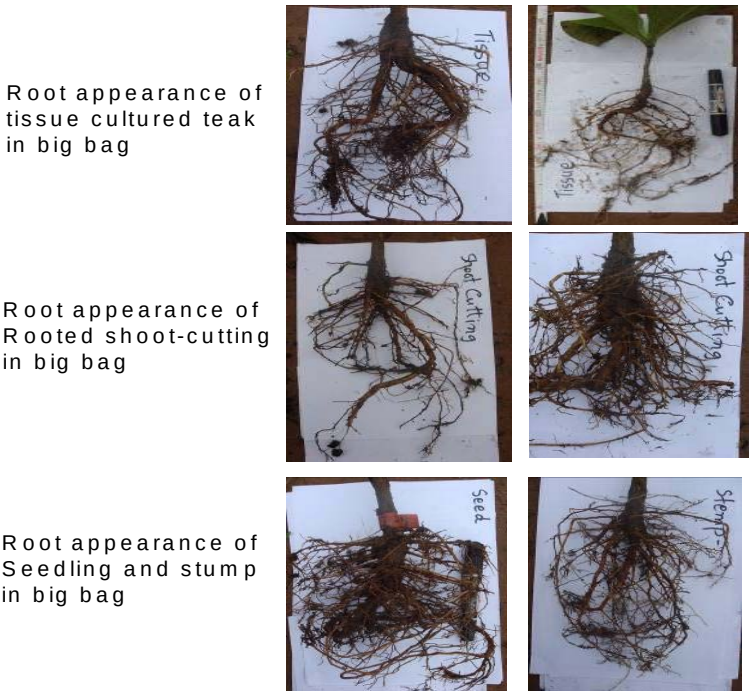


Figure 6 Root appearances of tissue cultured-teak, rooted shoot-cutting, and seedling and stump in big bags

6.3. Study-area III (Growth in the field)

The planting sites were located within same CFDTC compound and its training forest. The height of missing samples within each age was estimated by using regression model and all planting sites therefore exhibited at site quality 4/5 by checking teak-yield-table. It meant that all planting sites of teak tissue cultured plantation and teak provenances-collection planting found to be similar each other. Therefore, variation of site effect was excluded for further analysis in this study.

Regarding the results of predictions from regression model, average height of all plant origins were found at different ages and different site as shown in appendix 4 and 5.

Performance of all tested characteristics was generally influenced by variation of plant origins and age. For growth in the field, variations of growth characteristics (height, DBH and volume index), morphological appearances such as crown diameter, number of roots, root spread diameter, root depth and root volume index were assessed at three different ages (6, 5, and 4 year old) in experimental tissue-cultured teak plantation at CFDTC campus and training forest.

6.3.1. Mean performances of 'growth in the field'

Mean performances of characteristics for tested origins of plant at overall ages with grand mean, standard error and coefficient variations for all characteristics are given in Table 8.

Table 8. Comparison of mean value of origins for tested characteristics with their percent of coefficient variation (cv%) and standard error (se) (n=33)

No.	Characteristics	Origin of plant				Overall Mean	%cv	se
		Bd	Sd	Sh	Slg			
1	Height (m)	8.38*	7.05*	4.61	4.94	6.25	20.83	0.30
2	DBH(cm)	10.82*	9.39*	5.19	7.67	8.27	19.69	0.42
3	Vol-index (cm^3/1000)	55.85*	45100*	30890	38210	42.51	11.49	3.70
4	Crown dia(m)	3.61*	2.92*	1.89	2.5	2.74	22.83	0.12
5	Rt_qty(#)	5.33*	5.16*	4.50	5.33*	5.08	18.14	0.28
6	Rt_spred_dia(m)	2.73*	2.57*	1.9	2.44	2.41	24.1	0.10
7	Rt_depth(cm)	45.29*	40.29	38.1	42.05*	41.43	20.01	2.07
8	Rt-vol-index (cm^3/1000)	3.57*	2.02*	1.42	1.49	1.81	24.6	10.47

Bd= Bud, Sd= Seed, Sh=Shoot-tip, Slg=Seedling (Conventional), Rt=Root
* indicates that the mean value of tested characteristics perform greater than its overall mean value,

The results of overall mean and prediction value revealed that the characteristics of 'Bd' and 'Sd' demonstrated superior in height, DBH, volume index, and crown diameter than others. While 'Sh' was shown better in root depth, on the other hand 'Slg' performed slightly greater than the mean value of 'root-quantity' (number of root) and root depth. It could be prematurely proposed that teak trees from seed result slightly higher in number of root comparing trees from other propagation methods. Tissue cultured teak plantations were seen in CFDTC campus shown in figure 7. Measuring in the field and digging out the roots in the field shown in figure 8. Root appearances of tested teak tree (Tissue cultured and seeded teak tree) shown in figure 9.

6.3.2 Analysis of variance for all characteristics of origins overall ages

For height, DBH, volume index and crown diameter, significant differences ($p<.01$) were found for both ages and origins as presented in table 9. On the other hand, the result indicated that morphological characteristics of root quantity (number of root), root-spread-diameter, root-depth in addition to root volume index were found no significant differences among all tested origins of teak even though they were examined at different ages. It could be suggested that root performances within tested ages were no significant differences in height and diameter growth.

Table 9. Accumulated analysis of variance for all characteristics over all ages showing mean square values and significant different level (n=33)

Source of variation	d.f	Height	DBH	Vol; index	Crown dia	Root qty	Rt spread dia	Root depth	Root vol; index
Age	2	16.14**	99.43**	41933.1**	4.89**	4.78	0.54	125.35	606.5
Origin	3	13.70**	7.35**	6398.6**	0.71**	0.44	0.45	6.61	325.8
Residual	27	0.69	2.56	834.9	0.31	0.69	0.11	47.21	109.6

** indicates significant differences at $p<0.01$

(4 years old)

(5 years old)

(6 years old)

Figure 7. Tissue cultured teak plantation (4 – 5 - 6 years old)

Figure 8. Measuring in the field and digging out the roots in the field

Figure 9. Root appearances of tested teak tree (Tissue cultured and seeded teak tree)

6.3.3 Analysis of variance for all characteristics within each age

To explain more detail information for measured characteristics within each age, one-way ANOVA was used. Significant differences ($p<.01$) were found for height at age-6 and age-5 shown in table 10(a) and table 10(b). There is no significant difference in all tested characteristics at 4-years old teak plantation as shown in table 11-(c). Therefore the result concluded that height-growth of tested origins were found significant difference starting from 5 years old. This finding indicated that there is an initial establishment stage of height growth until 4 years old in this study.

Table 10. One-way ANOVA of all characteristics showing mean square value and significant level at each age class (n=9)

(a) 6 year-class

Source of Variation	d.f	Height	DBH	Vol index	Crown dia	Root qty	Root spread dia	Root depth	Root vol:
Origin	3	6.35**	0.71	2393.7	0.39	0.78	0.16	2.15	389.15
Residual	6	0.08	0.51	99.1	0.04	0.33	0.04	10.04	15.58

** indicates significant differences at $p<0.01$

(b) 5 years class

Source of Variation	d.f	Height	DBH	Vol index	Crown dia	Root qty	Root spred dia	Root depth	Root vol
Origin	2	12.25**	17.62	120.5	1.78	0.08	0.47	84.35	71.1
Residual	12	0.54	1.97	186.0	0.07	0.92	0.13	50.37	188.8

(**) indicates significant differences at $p<0.01$

(c) 4 years class

Source of Variation	d.f	Height	DBH	Vol index	Crown dia	Root qty	Root spred dia	Root depth	Root vol
Origin	2	1.36	2.58	588.1	0.75	2.33	0.40	142.65	205.06
Residual	6	0.16	1.17	283.7	0.29	0.22	0.02	22.94	41.42

6.3.4 Ranking the tested characteristics by using Duncan's multiple range test (DMRT)

The results of DMRT of means for group in homogeneous subsets are displayed for height, volume index, root quantity, root spread and root depth based on the use of "Harmonic Mean Sample Size" of 7.579 for tested variables at alpha 0.05 (table 11(a,b,c,d,e)). For height, "Bud" performed the best followed by "Sd" (Sterilized seed tissue culture), and normal seedling and "Sh" (shoot-tip tissue culture) were found in third group (table 11(a)). For volume index, it was observed the same trend with the height (table 11(b)).

The performances of root (root-quantity, root-spread and root depth), the most targeted interest in this study, were observed not significant differences (0.05) between tissue cultured-teak and normal teak trees in this study (table 11(c,d,e)).

Table 11 (a) Height

	Origin	N	Subset		
			1	2	3
Duncan	Sh	6	4.62		
	Slg	9	4.94		
	Sd	12		7.25	
	Bud	6			8.38

The error term is Mean Square (Error) =.681, (0.05 level)

Table 11(b) Volume Index (Square-root)

	Origin	N	Subset		
			1	2	3
Duncan	Sh	6	30.90		
	Slg	9	38.21	38.21	
	Sd	12		45.04	45.04
	Bud	6			55.85

The error term is Mean Square (Error) = 103.827, (0.05 level)

Table 11 (c) Root-qty

	Origin	N	Subset
			1
Duncan	Sh	6	4.5
	Sd	12	5.17
	Bud	6	5.33
	Slg	9	5.33

The error term is Mean Square (Error) = .587, (0.05 level)

Table 11 (d) Root spread dia (m)

	Origin	N	Subset	
			1	2
Duncan	Sh	6	1.9	
	Slg	9		2.44
	Sd	12		2.62
	Bud	6		2.73

The error term is Mean Square (Error) = .074, (0.05 level)

Table 11 (e) Root depth (cm)

	Origin	N	Subset	
			1	2
Duncan	Sh	6	38.1	
	Sd	12	40.53	40.53
	Slg	9	42.05	42.05
	Bud	6		45.30

The error term is Mean Square (Error) = 32.690, (0.05 level)

Subset= *Ranking for the value of tested origins (The bigger the number of subset, the more perform in tested characteristics)*

Bd= Teak tree from Bud culture
Sh=Teak tree from Shoot-tip culture
Sd=Teak tree from Sterilized seed culture
Slg=Teak tree from normal seedling

6.3.5. Relationship among tested characteristics

To assess the relationship among tested characteristics, pearson's correlation coefficient (r) was used. Result revealed that there was a positively significant relationship ($p<0.01$) among all tested characteristics shown in table12. Only root-quantity (number of main root) was found no relationship with all characteristics in addition to any other root performance but somewhat positive relationship with root depth was examined.

On the other hand, root morphological appearances except root-quantity were found fairly associated with the performance of crown diameter. There was a strong relationship between DBH and crown diameter (figure 10). The performance of root depth was only found slightly significant relationship with crown diameter. Root-spread-diameter was also observed significant relationship ($p<.01$) with DBH, volume index and

crown diameter. Based on this finding, it concluded that there is a positive-trend between root-spread-diameter, and DBH and crown development. Root quantity was obviously observed that there is no relationship with any other characteristics in this study.

Table12. Pearson's correlation coefficients (r) among all characteristics (n=33)

1.Height	1							
2.DBH	0.637*	1						
3.Vol_index	0.748*	0.959*	1					
4.Crowndia	0.697	0.897*	0.866*	1				
5.Root-qty	0.272	0.468	0.448	0.496	1			
6.Rt_spred_dia	0.476	0.638*	0.586*	0.663*	0.395	1		
7.Root_depth	0.261	0.543	0.495	0.57*	0.533	0.345	1	
8.Rootvolindex	0.546	0.688	0.738*	0.705*	0.443	0.549*	0.461	1
	1.	2	3	4	5	6	7	8

* indicates significant correlation at the 0.01 level

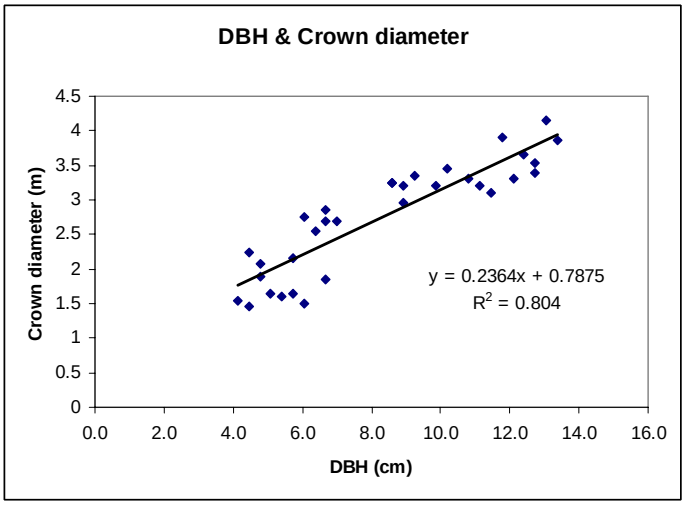


Figure 10. Relationship between DBH and crown-diameter

7. Conclusion

In this study, simple comparative analysis on variation of explants used in tissue culture techniques, variation of root performances in nursery, and variation of growth (height, DBH, volume index), and crown diameter and root morphological characteristic (root-quantity, root-spread-diameter, root-depth) of teak (*Tectona grandis*.L.f) were accomplished for different propagation methods (*in vitro*, shoot-cutting and seedling) as different study-areas at different ages (age-6,5,4). Results for each study-area were summarized as follows;

Study-area I (Growth in vitro at Tissue culture lab)

(1) For tissue culture techniques, the bud (terminal and lateral bud from teak-plus-tree) of explant was suggested as the best for ensuring good quality of teak plantlet than other origins of explant due to selecting from known and selected teak-plus-tree.

(2) Multiplication rate in mono-nodal segment of sterilized seed culture was found better but there might be affected by culture-media rather than explants.

(3) Rooting of shootlets in sterilized sand-box was suggested the best for survival, hardy and cost effective than rooting in culture-media.

Study-area II (Growth in Nursery)

(1) Variation of root development for all propagation methods was found out only in small-bag (7"x3"x ¾") but the similar performance was observed between tissue-cultured plant and rooted shoot-cutting. It can be concluded that variation of root development has only occurred in their initial stage of root formation.

(2) All teak plants grown in big-bag (12"x8") shown no differences of root-performance among all plant propagation methods.

Study-area III (Growth in the field)

This study area was the most important stage and its results might possibly summarize all previous achievements of study-areas I and II.

(1) The study found out that significant difference was remarkable only in height growth among origins of tissue cultured-teak. Tissue cultured-teak was accordingly the best in height growth in this study.

(2) Height growth of teak trees was no significant difference up to 4 year old in the field when there is no site-effect. It might be proposed that there is an early establishment stage for tested trees up to 4 year-old.

(3) Crown diameter was positively relationship with root performances (root-spread, root-depth) except root-quantity (number of roots). It can be suggested that crown-diameter is a good indicator for examining DBH and root-spread-diameter. The crown area or crown competition was a main indicator in the field for deciding thinning grade but root-spread-diameter (radial root development) should be also considered as parallel factor.

(4) This study found out that there was no correlation between root-quantity (number of root) and any other root characteristics in addition to height and DBH. Besides the root depth (vertical development) was not so important factor affecting height growth within tested ages in this study.

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However, any errors remain with the author.

Appendix 1. Result mean values on root observation of teak planting stocks in nursery

Method of propagation	Sources	Small bag (7"x3"x ¾")			Big bag (12"x8")		
		Main	medium	Ad- root	Main	medium	Ad-root
1. Tissue culture	Bud (Bd)	2.0	2.0	N	2.7*	3.0	N/M
	Sterilizedseed(Sd)	2.3	2.0	N	2.7*	3.3	M*
	Shoot-tip (Sh)	2.7*	1.7	N	2.3	3.0	N/M
2. Shooting cutting	Shoot from(THG)	2.3	3.3*	N/M*	2.0	4.3*	N/M
3. Seedling/stump	Seed	2.0	0.7	N	2.3	2.7	F/N
4. Stump	Seedling of seed	-	-	-	2.7*	3.3	M*
	Grand mean	2.3	1.94	N	2.5	3.3	N/M

THG= Teak Hedge Garden, F=Few, N=Normal, M=Many

* indicates that the value of tested characteristics performs greater than its overall mean value,

Appendix 2. Measurements of tested characteristics in the field

No.	Origin!	age!	Height (m)	DBH (cm)	Vol index (cm3)	Crown dia(m)	Root qty	Rt spred dia (m)	Root depth (cm)	Root vol index (cm3)
1	Bud	6	9.5	13.4	66678.0	3.86	5	2.6	40.64	4241
2	Bud	6	10	11.8	54470.8	3.9	5	3.2	45.72	3170
3	Bud	6	9.5	13.1	63540.6	4.15	6	3	48.26	4584
4	Sd	6	8.2	12.4	49625.3	3.65	7	2.4	43.18	2368
5	Sd	6	8.3	12.7	52839.5	3.4	6	2.6	48.26	2752
6	Sd	6	8.8	12.1	50560.4	3.3	6	2.4	45.72	2273
7	Slg	6	6.5	12.7	41380.3	3.53	5	2.8	48.26	1526
8	Slg	6	7	11.5	36096.3	3.1	6	2.6	43.18	1541
9	Slg	6	6.8	11.1	33144.0	3.2	6	2.8	48.26	1838
10	Sd	5	9.5	10.2	38706.5	3.45	5	2.4	49.53	4135
11	Sd	5	9.1	10.8	41856.2	3.3	6	2.8	45.72	2885
12	Sd	5	8.2	9.9	31354.3	3.2	6	3.2	50.8	4354
13	Bud	5	7.5	8.9	23395.8	3.2	4	2.4	43.18	2359
14	Bud	5	7	8.6	20304.2	3.25	5	2.2	45.72	2057
15	Bud	5	7.2	9.2	24092.9	3.35	7	3	48.26	2710
16	Sd	5	7.3	8.9	22771.9	2.95	4	3.2	33.02	866
17	Sd	5	10.2	6.7	17897.8	2.85	5	2.8	35.56	836
18	Sd	5	9.5	6.0	13645.5	2.75	5	2.2	33.02	718
19	Sh	5	6.2	6.4	9867.6	2.55	5	2	38.1	1520
20	Sh	5	6	4.5	4679.2	2.25	6	2.2	45.72	1138
21	Sh	5	6.8	4.8	6087.7	1.9	5	1.8	38.1	1368
22	Slg	5	4.9	5.1	4991.1	1.65	6	2.4	22.86	2493
23	Slg	5	5	4.5	3899.3	1.45	4	2.2	38.1	1059
24	Slg	5	4.8	4.8	4297.2	2.08	5	2	38.1	724
25	Sh	4	5.8	4.1	3900.1	1.55	3	1.8	33.02	630
26	Sh	4	6.1	6.0	8761.9	1.5	4	1.9	35.56	567
27	Sh	4	6.2	5.4	7129.3	1.6	4	1.7	38.1	717
28	Sd	4	6.2	8.6	17983.7	3.25	4	2.4	33.02	2523
29	Sd	4	5.4	6.7	9475.3	1.85	4	2.6	35.56	1831
30	Sd	4	6.5	5.7	8379.5	1.65	4	2.4	33.02	869
31	Slg	4	5.1	6.7	8948.9	2.7	5	2.6	38.1	1552
32	Slg	4	4.5	7.0	8666.0	2.7	5	2.2	48.26	1147
33	Slg	4	5	5.7	6445.8	2.15	6	2.4	53.34	1604

Appendix 3. Total work-done of culture-bottles for teak tissue culture project (2001-2002)

No.	Ex-plant	Culture process	2001	2002	Total
1	Bud	Induction	3720	4856	8576
		Multiplication	144	12	156
		Rooting	96	2	98
2	Sterilized seed	Induction	7924	4005	11929
		Multiplication	5053	875	5928
		Rooting	937	217	1154
3	Shoot-tip	Induction	7500	6060	13560
		Multiplication	490	422	912
		Rooting	230	60	290
	Total		**28095**	**18511**	**42603**

Appendix 4. Results of the average height of origins of teak tree at different ages

Origin of teak	Age		
	Age-6	Age-5	Age-4
Bd	9.67	9.12	7.73
Sd	8.86	8.31	6.92
Sh	7.55	7.00	5.61
Slg	6.34	5.79	4.40
Average height	**8.10**	**7.55**	**6.16**

Bd= Bud, Sd= Sterilized seed, Sh=Shoot, Slg=Normal seedling

Appendix 5. Height at different ages indicating site quality in teak –yield-table

Age	SQ1	SQ2	SQ3	SQ4	SQ5
4	11.4	9.76	8.1	**6.6**	**4.9**
5	14.3	12.2	10.1	**8.2**	**6.1**
6	17.2	14.6	12.1	**9.8**	**7.3**
10	20.4	17.7	14.9	11.9	8.8

SQ= site Quality