The (Un)Straight
Truth About Trees

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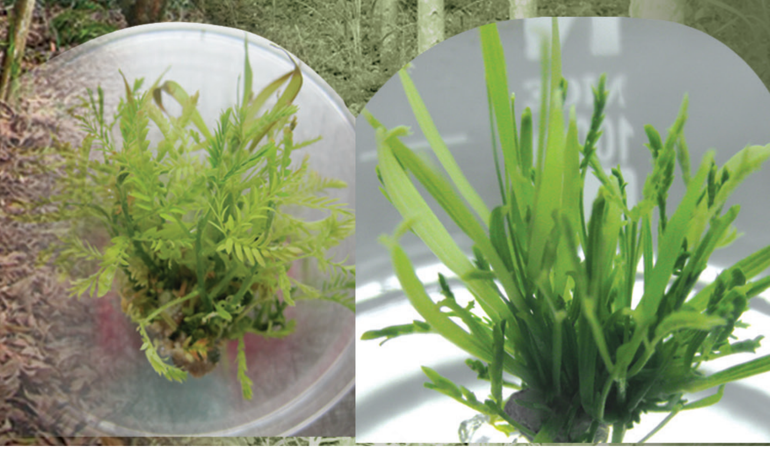

The (Un)Straight Truth About Trees

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The (Un)Straight Truth About Trees

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ABSTRACT

Forest and forest products have long contributed to the global economic base, provided environmental services and housing for biodiversity, including carbon sequestration, storage and supply for both flora and fauna resources. However, the available supply of the natural forests is insufficient to meet the growing demand for forest resources and forest products. Due to the constant exponential increase in the global population, there is always a need for more forest products and land for food production, which is usually located in existing natural forests. Consequently the existing natural forests are increasingly inevitably consumed by human developments for agricultural purposes, for food, unsustainable logging, urbanization, infrastructure and recreation facilities. Sustainable productivity within the confines of limited land areas is hence imperative to resolve this problem. One of the most feasible and practical strategies for this is the establishment of forest plantations that utilize improved planting materials.

The establishment of sustainable forest plantations is expected to improve economic growth and reduce pressure on natural forests as the sole source of wood for forest related industries. Related tree improvement programmes should thus focus on genetic selection and improvement and the development of appropriate viable propagation techniques involving variations at all levels. The core issue for sustainable productivity is an emphasis on improving yield quantity and the quality of wood related resources. Selection of quality resources is based on specific traits such as straight vs (un)straight trees targeted for specific products as specified by the industry. Therefore, improving the environmental and genetic (genotypes) variations, individually or in unison, will affect the ultimate tree productivity (phenotype). While it is unclear whether

the effects of genetic factors are more or less significant than environmental factors, the effects of the former are however more permanent.

This lecture series is thus aimed at reviewing the importance of tree improvement as a tool to acquire improved planting materials through selection and variation evaluation at species, provenance and progeny levels in selected multipurpose tree/crop species. This is expected to ensure sustainability of the selected materials targeted for specific products. It further aims to explore appropriate and workable propagation techniques and to identify, evaluate and predict the performance of various genotypes through genetic modification and the utilization of isozyme, RAPD, SSR, SNP and QTL in chemical and molecular assessments.

INTRODUCTION

Natural forests have contributed significantly to the socio-economic development in Malaysia. Export earnings for timber and wood based products increased by 5.1 % to reach RM20.52 billion in 2014 compared to RM19.53 billion in 2013 (MTIB, 2014). The projected supply of raw materials such as timber and wood based products for domestic needs are sufficient as of 2015 (Figure 1). At the same time, local production might not be sufficient to contribute towards further export earnings. The shortfall between global demand of these raw materials compared to the local supply is expected to be resolved by establishing forest plantations.

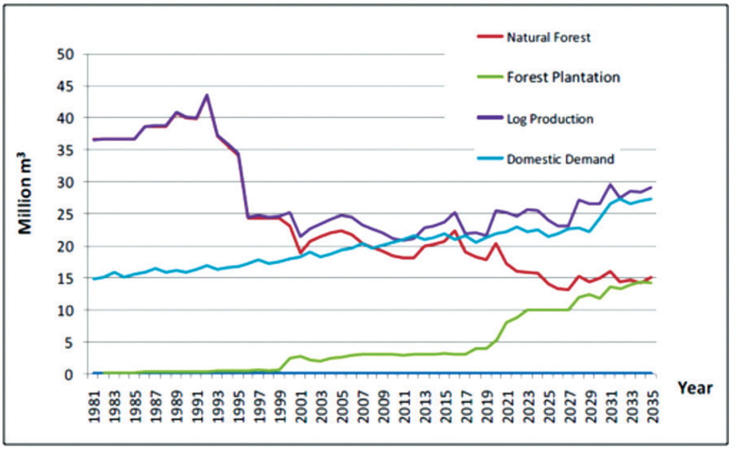

Figure 1 Projection of timber raw material production and domestic demand for timber industries
Source: MTIB (2010)

Establishment of sustainable forest plantations is a viable strategy to meet the increasing demands for wood products. For instance in Malaysia, approximately 0.97 mil hectares of forest plantation area has been established as of December 2013 (Forestry

Statistics Peninsular Malaysia 2013). They are planted with exotic species such as *Acacia*, teak, rubber, sentang and pine, among others. Productivity is the main aim of sustainable forestry and it should be harmonized with relevant environmental services. Both productivity and ecological processes are inter-connected and it is thus important that there is an integration of functions and objectives in such developments. Establishment of commercial plantations in Malaysia, through the Compensatory Forest Plantation Programme, was launched in 1982. These plantations were filled with fast growing species such as *Acacia mangium*, *Paraserianthes falcataria* and *Gmelina arborea,* which were to be harvested within a short rotation cycle of 15 years. The objective was to boost wood production to meet domestic needs and to sustain the development of the wood based sector in Malaysia.

The success of a forest plantation is entirely dependent upon the effective management of one or a few selected species through domestication programmes. Examples of some successful plantations include the *Pinus radiata* in New Zealand (90% of total plantation area) for sawn timber, panel products and pulp and paper and the *Eucalyptus grandis* in Brazil (70% of total plantation area) for pulp, paper and bioenergy. Thus, determining the appropriate species targeted for suitable end use is a good approach for sustainable short term plantation forestry. The Malaysian Timber Industrial Board (MTIB) thus set up Forest Plantation Development Sdn Bhd in 2006 to establish a large scale commercial forest plantation in Malaysia. The eight recommended species for the project were, *Acacia mangium* (Acacia), *Hevea brasiliensis* (Rubber), *Khaya ivorensis* (African Mahogany), *Tectona grandis* (Teak), *Neolamarkia cadamba* (Kelampayan), *Azadirachta excelsa* (Sentang), *Octomeles sumatrana* (Binuang) and *Paraserianthes* *falcataria* (Batai). These are all fast growing multipurpose tree species comprised of both exotic and local species.

The early growth performance results for these species were encouraging but subsequently there were indications of some limitations in growth productivity and the quality of the wood. Some drawbacks of some of these species included heavy branching, formation of multiple leaders from the base/forking, poor wood quality and genetic degradation with narrow genetic base. This could be due to the use of unselected seed sources or unsuitable sources for the selection of the right traits. It is thus important to consider evaluating the genetic variations of the appropriate traits in a particular species to improve the genetic quality of planting materials before they are used in a plantation programme. Hence, the aim of most tree improvement programmes should be to strive to combine good stem volume growth (quantitative) with high quality stem form, such as, straight trunk and circular bole with minimum branches (qualitative) for the production of superior trees for sawn timber or plywood production.

However, selection of wood/tree quality traits should be based on specific end uses, and aim for end-product quality attributes rather than intermediate wood attributes for various uses. As different end uses require different wood quality attributes, end uses have to be a consideration in tree breeding programmes. The end-use needs have to be assessed and evaluated in relation to each tree/species considered in a breeding programme and the end-product attributes should be weighed/incorporated through multiple-trait selection. Otherwise the selected resources may not be suitable for specific end uses. For instance, sawn timber or lumber can be effectively produced by utilizing straight trees with circular bole. However, trees cultivated for pulp and paper for pulpwood industries do not necessarily require these attributes. Most tree improvement programmes focus on maximizing wood productivity relating to economic importance. Ideally they should also include other intangibles of significance in urban forestry landscapes which are closely associated with health and aesthetic values. For instance it would make sense to select (un)straight trees with multiple trunks as they would provide natural grace, attractive shapes, offer easy pedestrian access and ample shade while at the same time acting as a natural wind breaker.

Breeders should also narrow down the number of traits to be included in a selection programme since only a few traits can be effectively improved at one time. Multiple-index selection is an approach to achieve multiple objectives through a multiple-population breeding system. Each trait (quantitative or qualitative) is assigned an economic weightage, thus making it possible to estimate the value of the designated products from the genetic materials. The decision on the traits selected for improvement programmes will thus depend on the economic value of the selected tree/species, cost management, species/tree response to selection and the duration/magnitude of changes in traits due to selection. It will also require some prediction on the responses to the selection through estimations of a number of growth parameters such as heritability, population stability in an environment, correlation among the traits and level of phenotypic variation.

FOREST GENETICS – CONCEPT AND SCOPE

Genetics is the branch of biology that studies the expression of the nature and transmission of genes. In this instance it concerns heritable variations and evaluates similarities and differences among trees related by descent. Genetics forms the basis for conservation, maintenance and management of ecosystems. The **Gene** is a molecular unit of heredity containing genetic information for a particular trait/characteristic that is passed to the offspring. All living things have many genes corresponding to various different biological traits, which are either visible or otherwise. Normally, these genes are encoded in long strands of DNA consisting of a chain made of four different nucleotide subunits, each composed of a five-carbon sugar (deoxyribose), a phosphate group and one of the four nitrogenous bases, adenine (A), cytosine (C), guanine (G) and thymine (T).

Combinations of these genes form the basis of all genetic variations and biodiversity through evolutionary adaptive change. Genetic variation is inter-linked with and inter dependent on functional and structural diversities which ensure that the particular species is able to adapt and survive well in a particular environment (Figure 2).

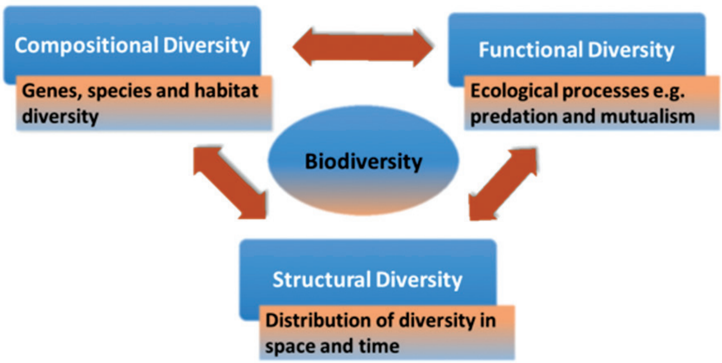

Figure 2 Inter-relationship of genetic diversity with the overall biodiversity systems

Forest genetics is the sub discipline of genetics dealing with variations and inheritance in forest trees. The genetic principles of trees are generally the same as with men, plants and even fruit flies, but the gene effects of forest trees, even at the individual tree level, are still unclear. The inheritance patterns and methods of experimentation vary among groups since trees are not model organisms. This is also because a characteristic of the forest is the complexity of effects involved in how they grow and develop. While the application of forest genetics does not necessarily provide important information on the cause and effect of genes on population and evolutionary dynamics, it has provided a diversity that can be used to design effective breeding and conservation programmes.

Forest tree improvement on the other hand, is the application of forest genetics to incorporate good silvicultural treatments to develop high yielding, healthy and sustainable plantation forests by maximizing genetic gain per unit time and area at the most economical cost. The impact of tree improvement programmes is similar to other breeding programmes involving crops and farm animals, i.e. increased yields and improved quality. Plantation development which involves effective tree improvement programmes would ensure sustainable wood production to overcome the issue of inadequate supply of raw materials to meet the ever increasing demands for forest products. It involves breeding trees through the traditional methods of selection and hybridization and sometimes new biotechnological tools, where appropriate. The practical implementation of tree improvement programmes normally involves the use of improved varieties developed in reforestation and afforestation programmes to increase the productivity, economic and social values of planted forests. This is an integral component of most plantation programmes.

IMPORTANCE OF FOREST GENETICS

The study of forest genetics can have several distinct and different goals. Genetic diversity studies can be linked to the management goal in identifying high yielding genetic resources for use in production forestry. At the same time, the knowledge and information from genetic diversity studies are essential not only to be used to design and monitor genetic conservation programmes but also to assess the effects of genetic erosion (lost) and the viability of natural forests due to threats such as timber and non-timber harvesting, fire and diseases (Nor Aini 1993, Nor Aini 1999, Namkoong *et al*. 2002, Rahayu *et al.* 2008).

Forest genetics presents a platform to study the genetic principles of a unique life form, due to its complexity. There are various organisms that interact with trees at many different time scales and generation intervals. In a forest ecosystem trees are the keystone species which are comparatively large in size, highly out-crossing (inter-mating), very heterozygous (*hetero* meaning different), highly variable individuals within a species and have long maturation time and life span. They are also vulnerable to long-term changes but show delayed reactions (Hamrick *et al.* 1992, Tsumura 2011).

Forest genetics enable the study of the natural evolution of a particular tree species on a large scale, covering its natural distribution and origins from different locations, known as provenance. The study of geographic variations within the native range has pertinent implications on genetics research and the patterns of genetic variation to be used for domestication of a tree species. Understanding the extent and patterns of variation guides us in testing planting seed sources in new environments, in studying the genotype and environmental interactions and subsequently to understand adaptation to the effects of past evolutionary forces and the ongoing evolution in the current environment. Kamis *et al*. (1994a), Kamis *et al*. (1994b), Nor Aini *et al*. (1996) and Eldoma *et al.* (2015a) reported that provenances of *Acacia mangium* and *Acacia auriculiformis* develop some deformities in stem form (e.g. crooked, low forking and poor stem form) when grown under different site preparation conditions and multi-locations (Figure 3).

Figure 3 Formation of multiple trunks from the base of the tree with crooked form from unimproved genetic materials of: **a)** *Acacia mangium;* and **b)** *Acacia auriculiformis*

Forest genetics principles are central to trees' improvement through the development of genetically improved materials or varieties for plantation systems. Genetically improved yield, health and product quality of these plantations would directly improve the economic and social values of the plantations (Rahayu *et al.* 2011, Qader *et al*. 2014a). Verification of improvement involves repeated cycles of selection, inter-mating and genetic testing

(Figure 4). It is initiated from broad-based genetic variation of wild or natural populations of tree species where the tree improvement programme aims to change gene frequencies for a few important traits of that species. Improvement objectives may range from high yielding varieties for commercial plantation, stress-resistance for rehabilitation of marginal and idle sites, improved nitrogen-fixing trees for agroforestry systems and improved varieties for bio-energy production for community or industrial plantations.

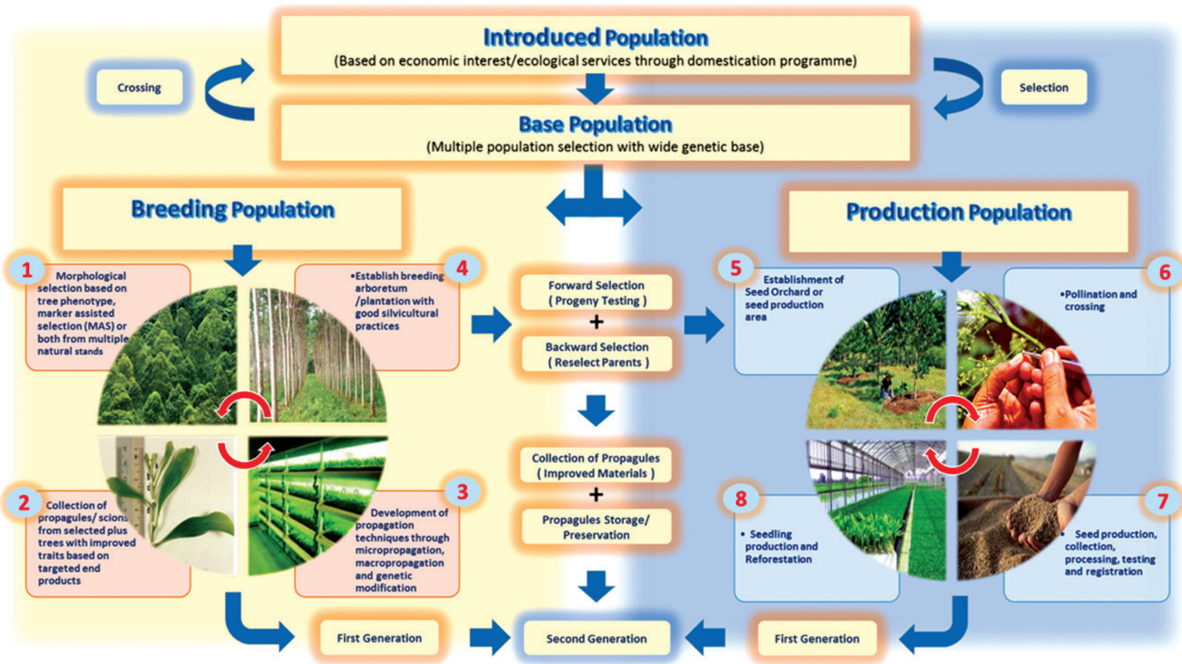

Figure 4 Developmental stages in tree improvement programme for sustainable production of improved materials (*Source:* Sures 2015)

Knowledge of general genetic principles and of the genetic structure of forest tree species is required to develop sound gene conservation strategies which is an essential component of sustainable forestry. As highlighted, genetic diversity as the core of adaptive value of species will ensure development of specific adaptation for survival and sustenance under changing environments. Conservation of genetic diversity has different purposes encompassing ecological, economic and aesthetic factors. Genetic variation, between and within species, enables the forest to carry out broad ecological functions that reflect the forest productivity. Gene conservation strategy for a particular species depends on the size of its geographic range and population genetic structure and can involve either *in situ* (on site) or *ex situ* (off site) methods. *In situ* conservation involves managing and maintaining genetic variation in native forests, as nature reserves and protective forests, while *ex situ* conservation involves growing trees in plantations outside their native location or storing germplasm (gene bank) in cold storage.

Forest genetics can help identify appropriate silvicultural treatments for sustainable management of natural and production forestry. Choice of silvicultural systems adopted for production forests in the tropical region is normally biased based on economic rather than ecological considerations. For instance, in Malaysia, the selective management system adopted for its commercial logging has some advantages for conserving stock for future use. Sustainable management of natural forests depends on their ability to regenerate. Successful regeneration and conservation of genetic diversity of its species is important for adaptation to environmental changes and impact on species productivity. Forest harvesting activities cause different forms and levels of disturbances to the forest ecosystem. For instance, felling of a big tree could damage several mediumsized trees and many saplings. According to Shaharuddin and Wikneswari (2011) careful implementation of reduced impact logging practices can reduce the severity of disturbances and thus improve the quality of forest management.

The use of biotechnology tools in forest genetics is a relevant strategy that aids in the breeding, selection and development of new tree varieties for the future. This involves the introduction of novel foreign genes, not naturally found in the target trees, through genetic engineering and use of appropriate molecular markers. Examples include genes resistant to herbicides (Slater *et al.* 2003), insecticidal *Bt* (Estruch *et al.* 1997), *Corynespora cassiicola* (Safiah *et al.* 2011) (Figure 5), stress tolerance and overexpression of GA-20 oxidase gene of *Arabidopsis thaliana* on *Hibiscus cannabinus* for increased fiber length and quality (Withanage *et al.* 2015) (Figure 6). Genetic engineering can also be used to possibly modify difficult genes associated with commercial values, such as, stem form and wood properties, as those traits are typically controlled by quantitative polygenic genes. Further, molecular markers have been utilized for the selection of pest and disease resistant genotypes, e.g. application of RAPD markers for gall rust disease in *Falcataria mollucana* (Rahayu *et al*. 2008, Rahayu *et al.* 2010) (Figure 7**)** and SSR markers for Root Knot Nematode (*Meloidogyne incognita*) in *Hibiscus cannabinus* (Nor Aini 2001, Tahery *et al.* 2011a, Tahery *et al*. 2011b) (Figures 8 and 9).

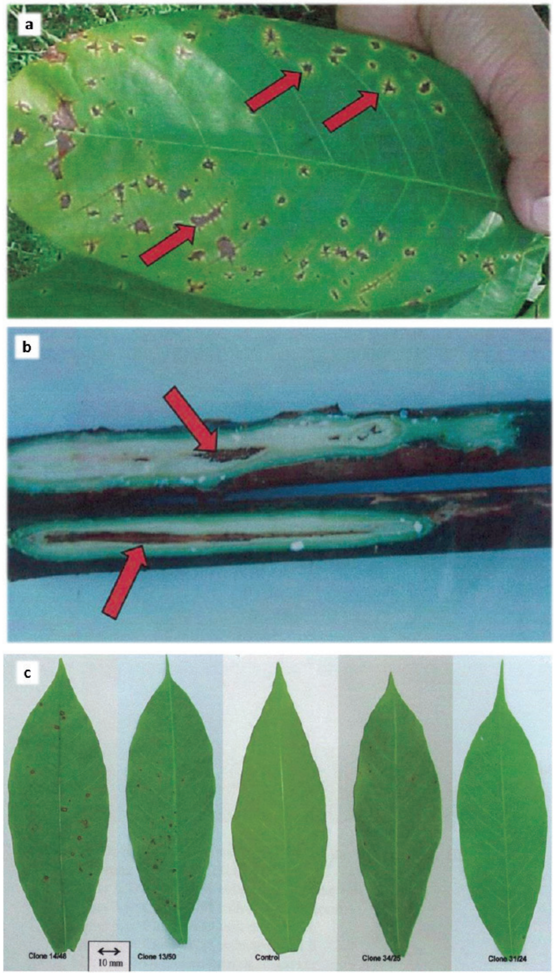

Figure 5 *Corynespora cassiicola* infection on *Hevea brasiliensis* trees planted in Malaysia: **a)** Signs of *C.cassicola* infection on young leaves showing circular or irregular greyish spots of varying sizes (indicated by red arrows); **b)** Infection in the core of the stem; **c)** Level of necrotic lesions on susceptible *Hevea* clones (clones 14/48 and 13/50) and tolerant clones (clone 34/25 and 31/24). Susceptible clones develop larger lesions compared to tolerant clones. (*Source*: Safiah 2011)

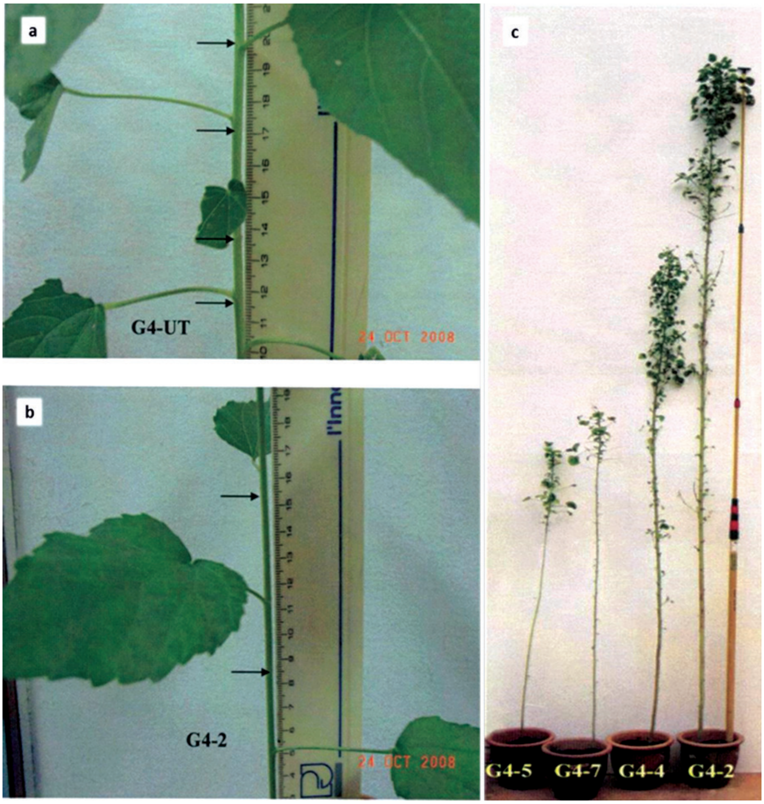

Figure 6 Overexpression of GA 20-oxidase gene of *Arabidopsis thaliana* in *Hibiscus cannabinus* for increased fiber length and quality. Effects of gibberellin on increase of internode length in: **a)** control plant (G4-UT) with four internodes occupied within 9.5cm (untransformed); **b)** transgenic plant (G4-2**)** with 2 internodes occupied within 11 cm; and **c)** vegetative growth phase of putative transgenic plant in variety G4, with different growth habit and flowering behaviour after 66 weeks. (*Source:* Withanage 2012)

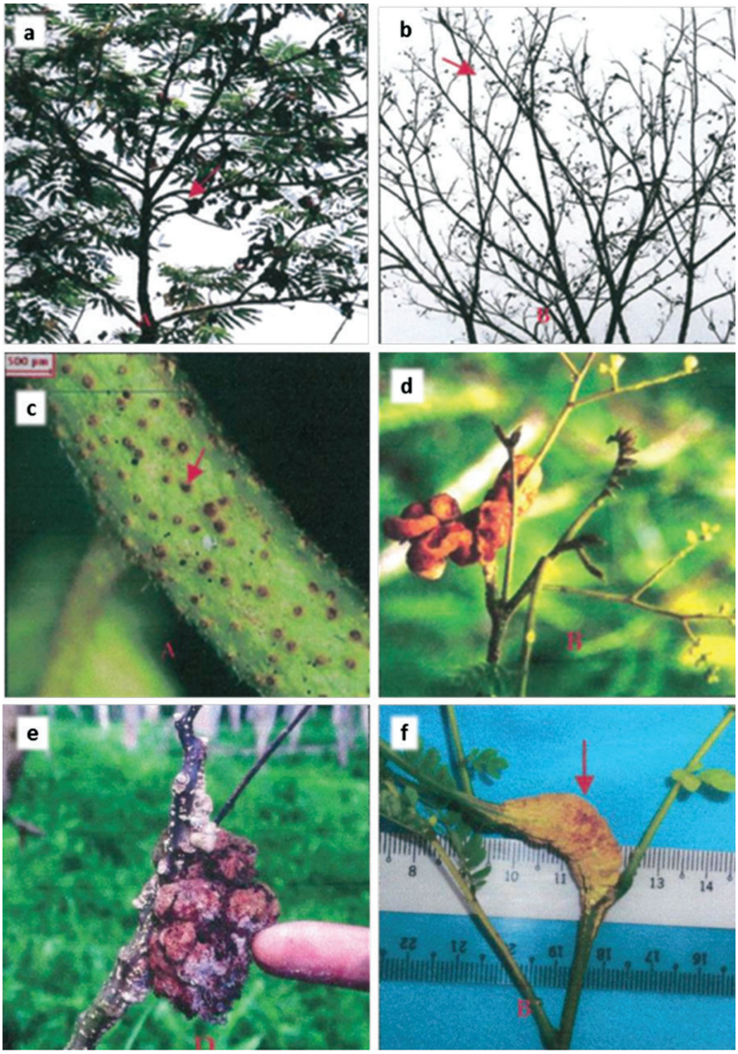

Figure 7 Gall rust disease infection on *Falcataria moluccana* trees planted in Sabah, Malaysia. **a)** and **b)** Formation of gall on adult tree; **c**) tiny spots on stem of juvenile seedling; **d**) deformities on seed pod; and (**e and f**) matured gall on tree branch. (*Source:* Rahayu 2007)

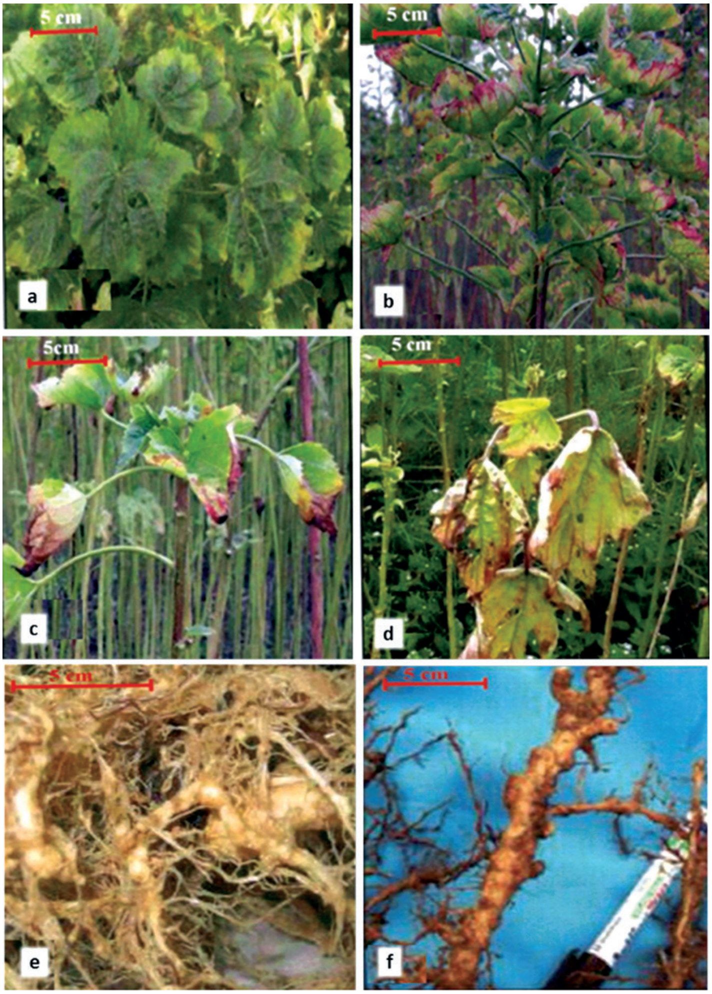

Figure 8 Root Knot Nematode (RKN) infection on 3 month-old *Hibiscus cannabinus* in Telaga Papan, Terengganu, Malaysia: **a**) and **b)** Symptoms of early stage of foliage infection; **c)** and **d)** Symptoms of advanced stage of foliage infection; and **e)** and **f)** Root galling caused by nematode (*M. incognita*) (*Source:* Tahery 2012)

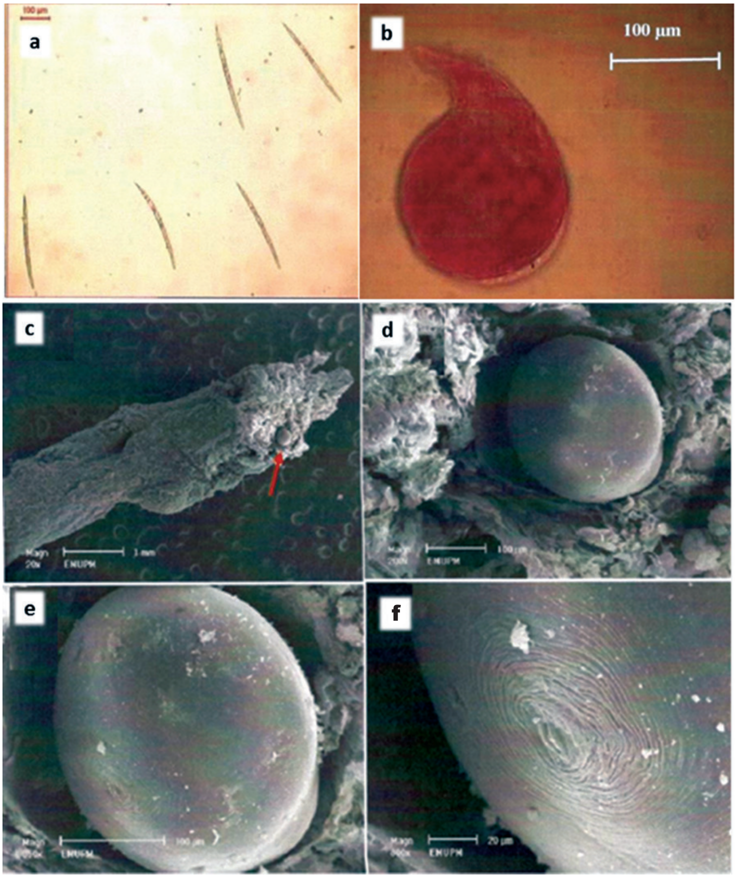

Figure 9 Nematode (*M. incognita)* isolated from infected root of *Hibiscus cannabinus:* **a)** larvae of RKN; **b)** Female RKN; Scanning electron micrograph of *M. incognita* under electron microscope at: **c)** 200µm and **d)** 550µm; (**e** and **f)** posterior part of adult female *M. incognita.* (*Source:* Tahery 2012)

SOURCES OF VARIATION IN FOREST GENETICS

Forest trees are genetically different and show tree to tree variations which are expressed as differences in the outward appearance, known as phenotypes. The phenotype is any characteristic of the tree that can be observed or measured. In other words, the tree that we observe is actually the result of the integrated effects of genotypes and the environment in which it grows, which are termed as the internal and external sources, respectively. The simple equation P=G+E (Phenotype=Genotype + Environment) is commonly used to indicate that the tree's genotype and environment are the underlying causes that together produce the final phenotype, as illustrated in Figure 10. The environmental factors are non-genetic factors, such as climate, soils and competition within and among species.

Genes residing in the genome of living cells of a tree determine the genotype. No two trees have exactly the same genotypes. However genotypes of two trees of the same species and from the same parent/family might have similar DNA sequences as compared to the genotypes from two trees of different species (Nor Aini 2014).

Trees bred from seeds normally express high phenotypic variation among themselves in a natural forest. No two trees from the same parent of the same species have exactly the same phenotype. Similarly, in humans, no two siblings from the same parents look alike or have the same phenotypes. There is variation from tree to tree in all characteristics, including size and form. However, trees bred from vegetative materials (clonal) are of the same genotype with little phenotypic variation, especially when they are raised on the same site/environment (Figure 11).

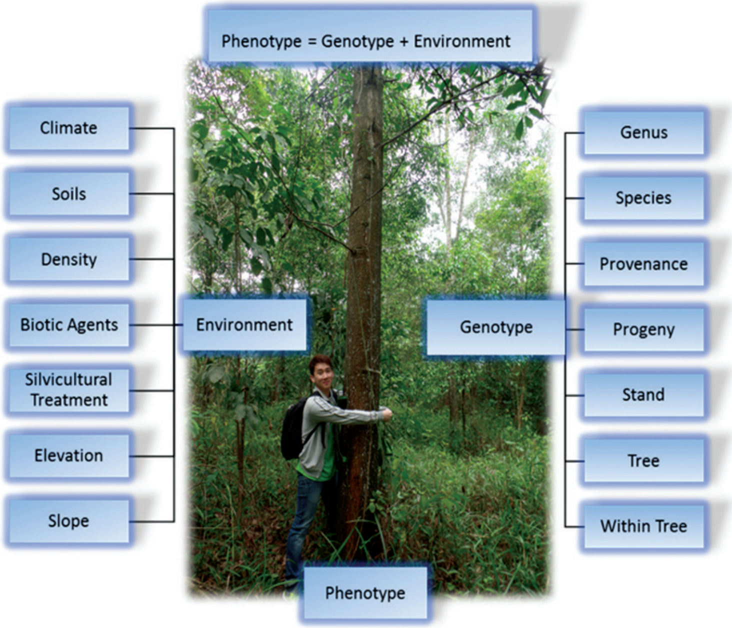

Figure 10 Different components of environmental and genetic factors that contribute to the phenotype of a tree

On the other hand, phenotypic variation can arise from a similar genotype exposed to a different environment, thus inducing changes for survival purposes. For instance, *Labisia pumila* evolved into two different varieties, namely, alata and longistyla, which display distinct differences in morphological traits when they grew in environments with different elevations. The ones found in the lowlands (var. alata) have smaller, thicker, greener and narrower leaves than those found in the highlands (Figure 12).

Figure 11 Phenotypic variation: (a) more variation from a two-year old plantation using seedlings raised from seeds at Sungai Siput, Perak; and (b) little variation from a two year-old plantation at Sitiawan, Perak raised using tissue culture plantlets.

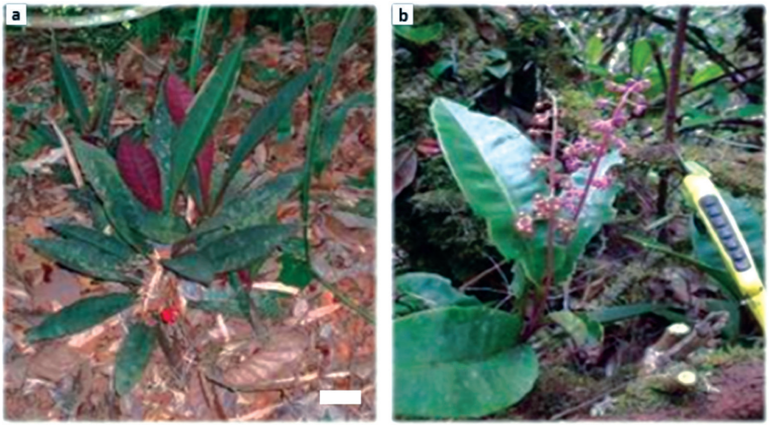

Figure 12 *Labisia pumila* in the: **a)** lowlands (var. alata) produced smaller, thicker, greener and narrower leaves) than that in; **b)** highlands (var. longistyla) *Note:* White bar = 1 cm

Above all, distinct phenotypic variation is also expressed by two different genotypes of the same age despite having the same growth environment. For instance, *Acacia aulococarpa* showed better growth performance than *A. auriculiformis* when grown on similar soil series (Figure 13).

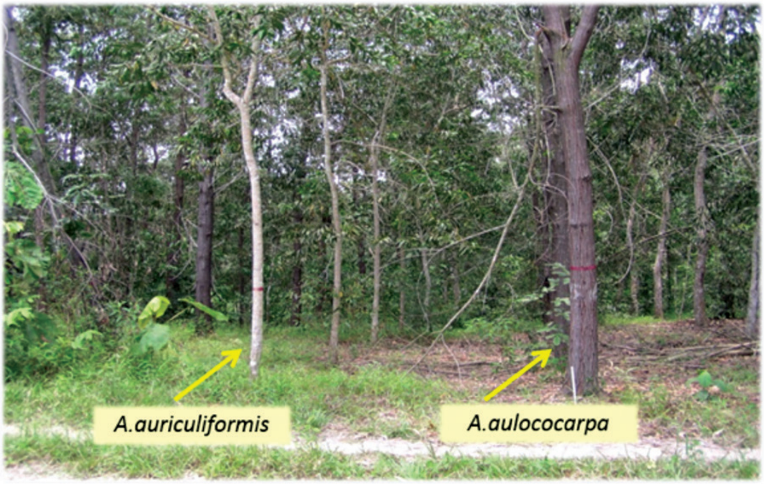

Figure 13 60-month old growth performance of different *Acacia* species raised in a similar environment (soil of Bungor series)

MEASURING GENETIC VARIATION

Assessment of genetic diversity can assist in identifying patterns of variation in genetic diversity for tree improvement and genetic conservation. Maintenance of genetic diversity in populations that are undergoing population changes, due to natural or human-induced events, is seen to be instrumental for population viability, adaptation and continued evolution (Muller-Starck *et al.* 1992; Templeton 1995; Namkoong 2001, Tsumura 2011).

Conventionally, measurements of genetic variation among tree species has been made based merely on evaluation of survival and tree growth performance from species, provenance or progeny trials. However, this exercise can be time-consuming, labour-intensive and costly as it depends on availability of appropriate plant materials required for continuous assessments and evaluation of genotype × environmental interactions to realize its long-term benefits.

Genetic variation in plant populations is measured using a broad range of approaches including: (i) the assessment of quantitative (continuous) characteristics such as seed set, growth rate and time to flowering (Hazandy *et al.* 2009a, Nor Aini *et al.* 2009b); (ii) observable heritable polymorphisms (multiple morphology) such as flower colour and tree form; (iii) chromosome rearrangements such as translocations and inversions (Nor Aini *et al.* 1994a); (iv) protein variation, in particular isozyme electrophoresis; and (v) nuclear and organelle DNA variation (Coates and Byrne 2005).

The first two approaches are common and widely used but they are time-consuming, especially when the characteristic under study such as height, is under the control of multi-genes. Advances in molecular biology and biotechnology however offer quick detection of genetic variation and characterisation of genotypes using molecular markers. Thus a wide array of DNA-based markers are now available that have allowed on-going refinement of approaches in the study of population-based variation and micro-evolutionary change. Molecular markers include isozymes, restriction fragment length polymorphisms (RFLPs), random amplified polymorphic DNAs (RAPDs), directed amplification of minisatellite DNA (DAMD), amplified fragment length polymorphisms (AFLPs), simple sequence repeats (SSR) and single nucleotide polymorphisms (SNPs) (Wickneswari 2011). Some of these markers, such as the isozymes, RFLPs and microsatellites are codominant (which allows the analysis of only one locus per experiment) single locus markers, while others such as RAPDs and AFLPs, are dominant (high-efficiency markers allow the analysis of many loci per experiment) multiloci markers.

These markers can be used effectively to provide genetic information that is complementary to forest inventory data and the regeneration status for sustainable management of forests, and also help in designing conservation strategies and breeding programmes. Molecular markers have many applications with respect to gene conservation of forest trees. They have been employed to understand the genetic structure of the natural population of several important commercial tree species. These include studies on *Bruguiera gymnorhiza* (Fukui *et al.* 2001, Minobe *et al*. 2010; Fukui *et al.* 2005), *Dryobalanops aromatic* (Lee *et al* 2000b), *Eurycoma longifolia* (Norifiza *et al.* 2003, Nor Aini *et al.* 2005a), *Hopea odorata* (Wickneswari *et al.* 1995), *Neobalanocarpus heimii* (Lee 2007), *Shorea leprosula* (Lee *et al.* 2000a, Cao *et al.* 2006), *Shorea parvifolia* (Tani *et al.* 2009) and other *Shorea sp* (Harada *et al*. 1994, Ishiyama *et al*. 2003, Nobuyuki *et al*. 2008), and *Mangifera* (Linatoc *et al*. 2006). A review by Tsumura (2011) on the mating system and gene flow using molecular markers revealed that outcrossing rates for Dipterocarp species in natural forests are generally high, 92.3% for *Dryobalanops aromatica* (Lee *et al.* 2000b), 83.7% for *Shorea leprosula* (Lee *et al.* 2000a), 96.3% for *Shorea curtisii* (Obayashi *et al.* 2002) and 96.3% for Shorea *parvifolia* (Tani *et al.* 2009), but that values are lower in logged-over forests viz 76.6% for *D. aromatica* (Lee *et al.* 2000b) and 52.20% for *S. curtisii* (Obayashi *et al.* 2002). The outcrossing rates of Dipterocarp are reported to be strongly influenced by the density of flowering trees (Fukue *et al.* 2007), flowering phenology and the types and behaviour of pollinators which govern pollen movement. These factors are the probable cause of the lowering of the out crossing rates. Thus, when the density of flowering trees is reduced, inbreeding depression increases when mating with relatives and selfing occur. Inbreeding depression in Dipterocarp occurs at all developmental stages, from seed formation, seed germination and seedling growth to sapling establishment (Tsumura 2011). Thus, genetic information on the genetic structure, gene flow and mating system are important and provide input for appropriate action plans for conservation and development of sustainable forestry.

THREATS TO FOREST GENETICS

As long as forests continue to be of economic, sociological and ecological importance, its genetic integrity will always be at risk. In other words, forest trees are exposed and are not immune to threats. According to FAO (2011), the rate of global forest loss is estimated to be around 13 million ha per year, from 2001-2010. The rate of deforestation and loss from natural causes is alarming with most reductions occurring in developing tropical countries. In addition, rapid socio-economic development in Southeast Asia, especially for infrastructure, agriculture and industrial development, has affected timber production and other forest ecosystem services. It was estimated that the total forested area in Southeast Asia was 214 million ha, which covers 49% of the total area, accounting for about 5.3% of the global forest area (FAO 2011). In terms of economic importance, forestry is critical for many of the Southeast Asian countries.

Threats can come in many forms and forces and they can be inter-related. The effects of threats can be variable, distinct, cascading and cumulative, and thus if they are not managed properly can lead to habitat loss, disruption and finally, species extinction. Tree populations of affected species become fragile as a result of being dislocated or eliminated along with the adaptive genes that are unique to them. Even if populations are not lost entirely, they may experience extreme 'bottlenecks' (isolation), resulting in loss of genes which had less or no expression before the bottlenecks. Thus, if populations continue to remain isolated and become smaller in number for several generations it can further reduce their genetic diversity and capacity for further adaptation. The other impact of reduced population size is increased chances of inbreeding (inter-mating with related individuals). When this effect becomes severe, the forest becomes unproductive, population viability declines, breeding population of trees, pollinators and other associated organisms reduce in vigour and can result in poor or even no regeneration. The consequence of these cascading effects will definitely affect the gene flow and mating system of the species (Tsumura 2011), as has been discussed earlier under the Section 'Measuring Genetic Variation'. Different kinds of threats include deforestation and defragmentation, pathogens, pollution, global climate change and narrowed genetic base resulting from intensive breeding programmes.

Assessment and maintenance of the genetic diversity of forests are important verifiers for the species' adaptive values and survival under changing environments. Although the forest has significant importance in socio-economic and ecological aspects, its genetic integrity is imperilled and not immune to threats. Understanding of the causes and consequences of these threats in relation to managing the genetic diversity at all levels is vital to ensure sustainable forestry development.

FOREST PLANTATIONS IN MALAYSIA

Peninsular Malaysia (131,600km^2) has a land area of 13.18 million hectares. It has a forested area of 5.83 million hectares (40.88%), which include 4.93 million hectares of Permanent Forest Reserves (PFR) (35.5%), 304,808 ha of state land, 585,119 ha of wildlife reserves and 4,884 ha of other reserved areas. The non-forested areas on the other hand stand at 7.33 million hectares (55.70%). The PFR consists of various types of forests and Forest Plantations is one of its components, constituting 0.32 million hectares (Table 1).

Table 1 Distribution of Forest Types under Permanent Forest Reserves (million ha) (*Source:* FSPM 2013)

Forest	Million Ha
Inland Forest	4.26
Peat Swamp Forest	0.25
Mangrove Forest	0.10
Forest Plantation	0.32

As of December 2013, the total area established for forest plantations was 0.09 million ha. Details of areas established for forest plantations for different species over the last ten years (2004-2013) are presented in Table 2. Most states in Malaysia established their plantation forestry based on short rotation cycles with a similar list of multipurpose exotic tree species, such as, *Acacia* and rubber. Generally, over the years, the trends of forest plantation establishment has been fluctuating but over the past three years the plantation areas have positively shown that they either increased or stayed constant for all species. However, there has been a shift in the choice of species preferred for the purpose of plantation forestry in Malaysia. There has been a reduction in areas planted with pine and an increase in areas planted with rubber. As for *Acacia*, there was a sharp drop in the planting area in 2011 but it steadily increased in the subsequent year.

Table 2 Forest plantations established as at 31 December 2013 (in hectares) (*Source:* FSPM 2013)

Year	*Acacia*	Teak	Pine	Rubber	Sentang	Others	Total
2004	61,124	3,016	4,193	2,317	1,482	2,923	75,055
2005	58,878	3, 016	3,124	2,195	1,307	2,673	71,283
2006	58.224	2,789	2,937	1,626	355	17,533	83,464
2007	59,767	2,743	2,292	17,443	352	21,944	104,541
2008	55,503	2,698	2,667	17,544	281	22,376	101,069
2009	59,486	2,709	2,667	21,936	281	21,673	108,752
2010	74,438	2,709	716	22,401	281	8,112	108,657
2011	28,978	2,901	374	21,930	881	6,521	61585
2012	41,989	2,847	374	34,877	868	6,489	87,444
2013	46,126	2,847	374	40,372	868	7,209	97,796

This could be due to incidences of heart rot and multiple leader formation in the *Acacia* which in turn affected the productivity of quality logs of desirable size during the 15 years rotation (Kamis *et al*. 1994a, Kamis *et al*. 1994b, Nor Aini *et al.* 1994b, Nor Aini *et al.* 1996, Eldoma *et al.* 2015a, Eldoma *et al.* 2015b). In addition, Hashim *et al.* (1995) also reported that *Acacia* trees which were susceptible to heart rot damage showed poor volume growth (Figure 14). Rubber, teak and others, including *Shorea leprosula* (meranti tembaga), were thus sought after because they have been noted to be promising, based on their growth rate and adaptability (Krishnapillay 2002). In fact the promotion of rubber was vigorous because of the introduction of the Latex Timber Clone (LTC) which exhibited good timber growth and latex production (Safiah *et al.* 2011, Junaiza *et al*. 2012).

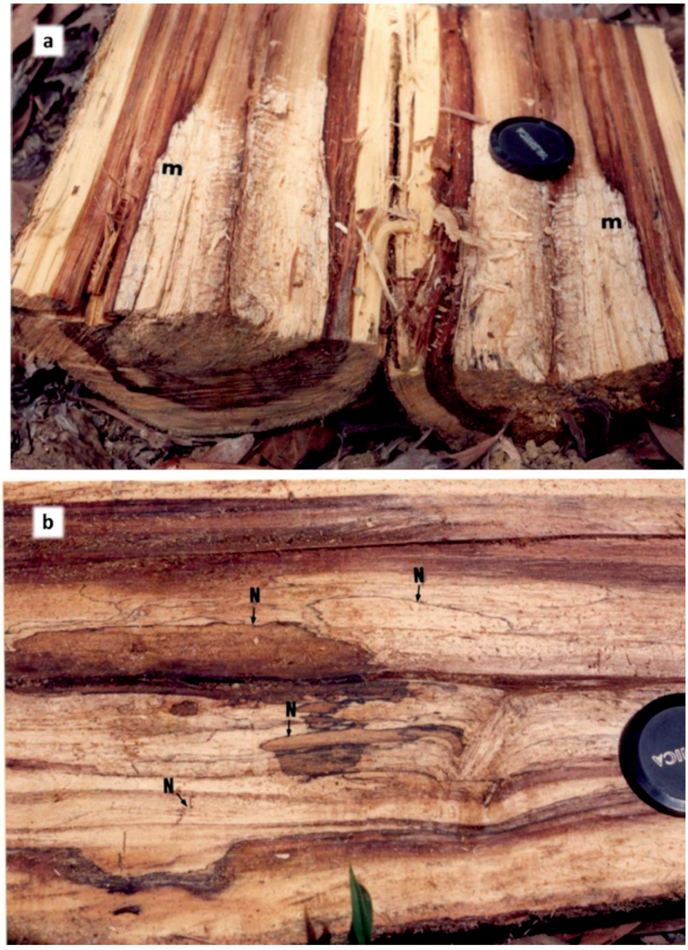

Figure 14 Heart rot disease infection on *Acacia mangium* wood: **a)** Advanced stage of decayed wood (lighter in color, fibrous and spongy in texture) at the core of the stem showing presence of fungal mycelium; and **b)** Longitudinal section of heart-rotted stem showing the zone lines during wood decay *Note:* M= fungal mycelium; H= Zone lines. (*Source:* Hashim 1993)

In fact, currently the rubber trees have become the most sought after plantation species for the production of wood products, especially furniture. Since the smallholding sector is also unable to satisfy the national demand for rubber wood, alternative sources of rubber wood are needed, and one of the sources is rubber plantations. The Malaysian Rubber Board (MRB) has extensive experience in rubber cultivation and has produced and selected latex timber clones and/or timber clones that are most suitable for production of latex and timber or timber only. The clones and agronomic practices are aimed at maximizing tree growth with the view of obtaining better economic returns. Examples of rubber clones include RRIM 2000, RRIM 2025, RRIM 2004, RRIM 2008 and others. The rubber forest plantations can be divided into two types: rubber wood and latex plantation and rubber wood plantation. In the rubber wood and latex plantations, timber is the primary product and latex is the secondary product. In the rubber wood plantation, the plantation is solely for rubber wood extraction and the trees are not tapped for latex.

In Malaysia, the concept and practice of forest plantations can be traced back to the last century (1800's). The record of planting forest species dates back to 1880 when concerns for the loss of desired species was first noted (Nor Aini 1999). The Forestry Department carried out most of the trial plantation work but records were meagre. Initially, the focus was on the exotic species, but subsequently local species were tested with the notion that they had better growth and better adaptability to local conditions. However, during this period, many trials were lost and abandoned when officers got transferred. Interest in this field remained low for many years and its practice was without any momentum in the forestry sector. Plantations were grown on a very small scale. This was due to the abundance of timber from natural forests as well as the relative low prices for management which did not provide any need to start big scale forest plantations.

However, in the early 1970s, it began to dawn upon forest authorities that productivity could not be increased to meet the needs of the country even if the natural forests were sustainably managed. As the 1980s approached, most of the state land forests were converted for development and forest resources became more and more limited to the Permanent Reserves only (Krishnapillay 2002). The Permanent Reserves, however, were poorly stocked and in the meantime, wood industries were developing. It was obvious that the demand for timber faced by the country was beyond the ability of the natural forests, more so in the long term. In fact, Chong, 1979, had speculated that the country would face a significant timber shortage in the future. This was due to the irregular supply of timber from the natural forests, the reduction of natural forests and the inability to manage natural forests properly. However, sustainably managed forests were also unable to meet the growing need. Evans (1992) also noted that the productivity of a well-managed plantation was four times higher than a well-managed natural forest.

In order to meet the shortfall of timber, the Forestry Department planned a forest plantation project for general utility timber. Under this scheme, 188,200ha of plantations were to be established by 1995 (Krishnapillay 2002). Commercial forest plantation development in Malaysia is relatively new compared to other regions like Europe and North America. The Malaysian Government, recognizing the potential and the need to sustain the future growth of the timber industry in the country, proceeded to provide certain incentives to promote investment in forest plantations.

The commercial forest plantation sector in Malaysia has however been growing at a very slow pace. Amongst the major constraints faced are:

- High capital and high risk involved in forest plantations, particularly since the 1997/98 economic depression where most private and public companies lost their financial capacity
- Lack of suitable and cheap land for large scale forest plantation development
- Long gestation period required for forest plantation projects
- Lack of technical knowledge in the choice of species and appropriate management regime, especially for the much sought-after indigenous species
- Insufficient government incentives to promote forest plantation development
- Lack of confidence regarding the return on investment on the part of investors and the banking sector

Further issues and challenges that need to be addressed are the reduction in log production from natural forests, the introduction of small logs in the industry as compared to big logs previously, the unveiling and introduction of the lesser known species as future products, plantation size growth as well as the transition from solid wood to reconstituted wood. Plantation forestry is hoped to be able to help solve and reduce these challenges.

The burden of log production from natural forests can be reduced by establishing plantations. As the supply of timber from natural forests declines, plantation forestry will have to supply more of the country's timber. Plantations will have to bear the main burden of the country's timber needs and will have to replace, in terms of quantity and quality, what is available from the natural forest. However, it is important to select suitable species which can generate income and have acceptable rotation rates.

Among the factors that will determine a good choice of species are:

- The availability of planting stock of predictable performance
- The ability to thrive under plantation conditions with minimal management intervention
- Plantation species that are adaptable across a variety of site conditions, from waterlogged valleys to dry ridges, as such a range of conditions may exist in a single large plantation

Reviews of the growth performance from planting trials of various introductions, resulted in the following criteria for species selection for forest plantations:

- High survival and successful growth after planting
- Good initial growth
- Tolerant of some shade and site competition
- Natural self-pruning and a good natural bole
- Generally resistant to insect and fungal attacks
- Timber of good economic value for general utility use

Initially, the forest plantations were dominated by exotic species such as *Acacia*, *Paraserianthes*, *Pinus*, *Eucalyptus*, *Gmelina* and others. Subsequently these species were reduced because of the inconsistencies in the results of plantings. When these exotics were selected, it was because they were species with good, desirable characteristics that had proven themselves under plantation conditions.

The species selected for plantations were grouped into two categories: the principal and substitute species. The principal species are the ones that have already been accepted for plantations in Peninsular Malaysia, whereas the substitute species are those that may prove to be good plantation species but at present labour under one or more constraints such as limitations of planting stock. These constraints can be overcome, in time with genetic improvements, propagation and setting up seed orchards and the development of other propagation techniques that are inexpensive. The principal species include *Azadirachta excelsa, Dyera costulata, Endospermum malaccense, Hevea spp., Hopea odorata, Khaya ivorensis* and *Tectona grandis.* The substitute species include species like *Dryobalanops aromatica, Octomeles sumatrana, Shorea leprosula, Shorea marophylla, Shorea parvifolia* and *Switenia macrophyla* (Zuhaidi *et al*. 2002).

Any plantation will include a number of site conditions. Species that are able to adapt to these site conditions are preferred if a plantation opts to focus its resources on a single species. However, it is also possible to select a number of species that are suitable for different sites and include them in a single plantation. Although management thus becomes more complex, productivity and maximum output can be attained. In Malaysia, plantation forestry is an important strategy to overcome the timber shortage. Thus, with the problems highlighted above, researches on genetic improvements and propagation have been conducted on multipurpose tree species to increase productivity. The species stated above are not only fast growing, but also offer a number of potential uses, timber and non-timber products and other services. Nevertheless, recent plantings have not relied on improved genetic materials hence, results have been inconsistent. High productivity of future plantations of these species can only be assured if improved seeds and planting materials are used for their establishment (Figure 15).

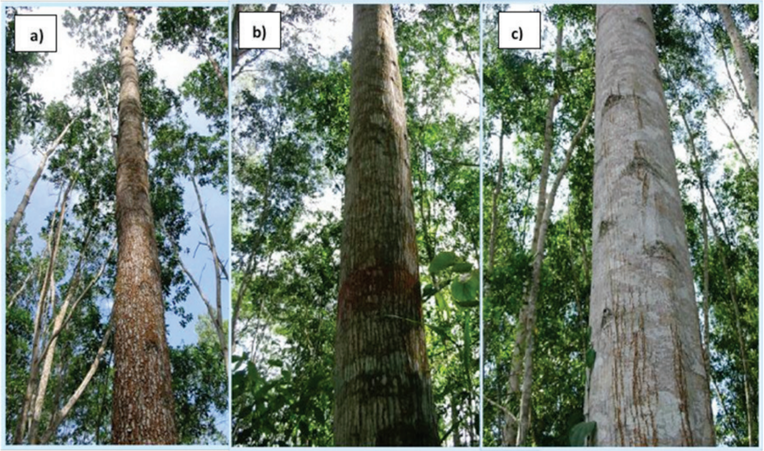

Figure 15 Plus tree identification through early morphological selection for mass propagation of clonal materials: a) *A.mangium;* b) *A.auriculiformis;* and c) *A*.hybrid (*A.mangium* x *A.auriculiformis*)

GENETIC VARIATION AND IMPROVEMENT OF SOME IMPORTANT TREE SPECIES

Tree improvement research was undertaken with two objectives which were to: (i) select and improve several genotypes of the chosen species; and (ii) to develop appropriate technologies of mass propagation of the improved materials. Species which were tried are of both exotic and indigenous. The former include, selected *Acacia* species (*A. mangium, A. auriculiformis, A. crassicarpa and A. aulocorcarpa*), *Khaya ivorensis*, *Tectona grandis* and *Eucalyptus* species, while the latter are *Azadirachta excelsa* and selected *Shorea* species. The research comprised three components: trials of *Acacia* progenies and genotypes (Nor Aini and Kamis 1992, Nor Aini *et al*. 1994b, Nor Aini *et al.* 1994c, Kamis *et al*. 1994a , Kamis *et al*. 1994b, Kamis *et al*. 1996, Nor Aini *et al.* 1996, Mahat *et al*. 2001, Nor Aini *et al.* 2007a, Senin *et al.* 2007, Eldoma *et al*. 2015a), multilocational trials of *A. excelsa* and *Shorea leprosula* (Kamis and Nor Aini, 1997, Nor Aini *et al.*1998a, Hazandy *et al.* 1999, Kado *et al.* 2001, Nor Aini *et al*. 2002) and the development of cloning techniques for mass propagation of improved materials, i.e. either by adopting micropropagation through tissue culture or macropropagation through rooting of cuttings and marcotting. The former involved development of protocols for *A. auriculiformis* (Haliza *et al.* 2012)*, A. crassicarpa* (Nor Aini and Griffin 1998, Griffin *et al.* 1999a, Griffin *et al.* 1999b, Nor Aini *et al.* 2000, Griffin *et al.* 2014), *A. excelsa* (Juddy and Nor Aini 1997, Nor Aini and Juddy 1997, Nor Aini and Foan 1997, Juddy *et al*. 1997, Nor Aini *et al.* 1998b, Kamis and Nor Aini, 1999, Nor Aini *et al.* 2008)*, Aquilaria malaccensis* (Ridzuan *et al.* 2009)*, Eucalyptus camaldulensis* (Qader *et al.* 2014b), *S. parvifolia* (Aziah *et al.* 2013) *, T. grandis* (Nor Aini *et al.* 2009a), and *K. ivorensis,* while the latter examined various factors controlling the rooting of cuttings and marcots of *A. excelsa,* selected *Shorea* species (Nor Aini and Ling 1993, Nor Aini and Liew 1994, Nor Aini and Liew 1997) and *Acacia* species *(*Kamis *et al.* 1997, Kamis *et al.* 1998). Table 3 summarizes the details of the clonal propagation conducted on several important multipurpose tree species in Malaysia.

Table 3 Regeneration of multipurpose tree species through macropropagation and micropropagation

Species	Technique	Reference
Acacia auriculiformis	Micropropagation	Haliza *et al.* (2012)
Acacia auriculiformis	Micropropagation	Haliza *et al.* (2000)
Acacia crassicarpa	Micropropagation	Griffin *et al.* (2014)
Acacia crassicarpa	Micropropagation	Griffin *et al.* (1999a, 1999b)
Acacia crassicarpa	Micropropagation	Nor Aini and Griffin (1998)
Acacia crassicarpa	Macropropagation	Kamis *et al.* (1998)
Anisoptera scaphula	Macropropagation	Hossain *et al.* (2014c)
Aquilaria malaccensis	Micropropagation	Ridzuan *et al.* 2009
Azadirachta excelsa	Micropropagation	Nor Aini *et al* (2008)
Azadirachta excelsa	Micropropagation	Juddy *et al.* (1997)
Azadirachta excelsa	Micropropagation	Nor Aini *et al.* (1998b)
Azadirachta excelsa	Micropropagation	Juddy and Nor Aini (1997)
Calamus logisetus	Macropropagation	Haider *et al.* (2014)
Entada rheedii	Macropropagation	Hossain *et al*. (2014a)
Eucalyptus camaldulensis	Micropropagation	Qader *et al.* (2014b)
Gonytylus bancanus	Macropropagation	Nor Aini *et al.* (2010)
Hibiscus cannabinus	Micropropagation	Withanage *et al.* (2013)
Labisia pumila	Macropropagation	Rozihawati *et al.* (2006)
Labisia pumila	Macropropagation	Nor Aini *et al.* (2007b)
Podocarpus nerifolius	Macropropagation	Hossain *et al.* (2014b)
Shorea acuminata	Macropropagation	Nor Aini and Ling (1993)
Shorea leprosula	Macropropagation	Nor Aini and Liew (1994)
Shorea parvifolia	Micropropagation	Aziah *et al.* (2013)
Shorea parvifolia	Macropropagation	Nor Aini and Ling (1993)
Terminalia beleria	Macropropagation	Hossain *et al.* (2014d)
Terminalia chebula	Macropropagation	Hossain *et al.* (2013)
Tectona grandis	Micropropagation	Nor Aini *et al.* (2009a)

Results of the first component of *Acacia* provenance and progeny trials relating to genetic variation of growth performance (Nor Aini and Kamis 1992, Kamis *et al*. 1994a, Nor Aini *et al.* 1996, Nor Aini *et al*. 1994b, Nor Aini *et al*. 1994c, Venkateswarlu *et al.* 1994, Kamis *et al.* 1996, Senin *et al*. 2007), multiple leader (ML) formation (Eldoma *et al*. 2001, Eldoma *et al*. 2015a, Eldoma *et al*. 2015b), selected physical and mechanical properties and selected physiological properties (Mahat *et al.* 2001, Nor Aini *et al.* 2007c, Nor Aini *et al*. 2013) revealed significant differences between species, regions, provenances and progenies. In terms of growth performance, *A. mangium* consistently outperformed the other three *Acacia* species, both at 24 and 48 months respectively (Table 4). Further, provenances from the region PNG outperformed the QLD provenances for all four *Acacia* species tested (Table 5).

Table 4 Mean height and DBH of four *Acacia* species after 24 and 48 months

Species	24 Months			48 Months		
	Height	DBH	CR	Height	DBH	CR
A. mangium	5.57[a]	6.76[a]	1	19.58[a]	14.66[a]	1
A. crassicarpa	5.41[b]	5.90[b]	2	15.41[b]	12.64[b]	2
A. auriculiformis	4.30[c]	4.34[c]	3	**9.09[d]**	10.35[c]	4
A. aulacocarpa	3.74[d]	3.48[d]	4	**11.29[c]**	10.01[c]	3

Table 5 Mean height and DBH of *Acacia* provenances after 24 and 48 months

Species	Region	Provenance	24 Months			48 Months		
			Height	DBH	CR	Height	DBH	CR
A. mangium	PNG	Bensbach WP	5.98^{b}	**7.63^{a}**	2	**22.50^{a}**	15.74^{a}	1
	PNG	SW of Boset WP	**6.23^{a}**	7.36^{b}	1	20.25^{b}	**15.78^{a}**	2
	QLD	Captain Billy Road	5.01^{ef}	6.18^{d}	3	18.13^{c}	12.88^{cd}	3
	QLD	Russel & Gap CK	4.34^{g}	4.92^{g}	10	11.73^{hi}	9.69^{hi}	10
A. crassicarpa	PNG	Bimadebum WP	5.74^{c}	6.42^{c}	5	16.74^{cd}	13.13^{c}	4
	PNG	Bensbach WP	5.64^{c}	6.10^{d}	7	15.76^{de}	14.49^{b}	5
	QLD	Caludie River	5.08^{e}	5.29^{f}	4	15.04^{ef}	12.04^{de}	6
	QLD	Chilli Beach	5.26^{d}	5.85^{e}	9	14.27^{efg}	11.21^{ef}	8
A. aulacocarpa	PNG	Arufi E Morehead WP	4.25^{g}	4.16^{i}	12	14.84^{efg}	11.71^{e}	7
	PNG	W Morehead	3.84^{h}	4.05^{j}	15	13.69^{fg}	13.24^{c}	9
	QLD	Samford	**2.79^{j}**	**2.23^{m}**	16	8.13^{j}	**6.50^{j}**	13
	QLD	3K S Mt Larcom	3.68^{i}	2.89^{l}	14	7.83^{j}	9.08^{i}	14
A. auriculiformis	PNG	Mibini	4.90^{f}	5.24^{f}	6	13.18^{gh}	10.61^{fgh}	11
	PNG	Bansbach	4.40^{g}	4.70^{h}	12	10.86^{i}	10.26^{gh}	12
	QLD	Wenlock River	4.34^{g}	4.04^{j}	8	7.31^{j}	10.76^{fg}	15
	QLD	Boggy Creek	3.63^{i}	3.56^{k}	11	**6.55^{j}**	7.19^{j}	16

Examination of growth at different time periods, i.e. 24 and 48 months, revealed the inconsistent trend in ranking of species and provenance. The best performers at 24 months did not remain superior all the way through until 48 months. Some of those which were initially low-performers were able to compete and change their ranking to better performers over 48 months. For instance, at 24 months, the order in terms of height, DBH, survival and stem form was: *A. mangium* > *A. crassicarpa* > *A. auriculiformis* > *A. aulacocarpa,* whereas at 48 months, the order changed slightly, especially the contraposition of the last 2 inferior species, i.e. *A. mangium* > *A. crassicarpa* > *A. aulacocarpa* > *A. auriculiformis*. Similarly, provenance Bensbach WP (PNG) of *A. mangium* which was ranked second at 24 months became first ranked at 48 months (Tables 4 and 5).

It was also established that good growers (those having good growth) also produced good physical and mechanical properties (Mahat *et al.* 2001, Nor Aini *et al*. 2013). For example, provenance Bensbach WP (PNG) which recorded the most superior growth in terms of height, DBH and form at 48 months produced significantly the highest specific gravity (SG), MOR and MOE, with the lowest radial and tangential shrinkages, indicating that the wood from the top performers was also stronger (Nor Aini *et al.* 2005b, Nor Aini *et al*. 2013).

Even though these *Acacias* had been proposed for timber production in a short rotation, this proposition was impeded by ML and heart rot formation (Nor Aini *et al*. 1994b, Hashim *et al.* 1995, Eldoma *et al.* 2001, Eldoma *et al.* 2015a). Of the two ML is considered the most limiting for log production of desirable size in 15 years rotation and ML can definitely affect the productivity of wood. Results from the study on the causes of ML formation and its variations revealed that its occurrences were significantly variable with respect to species, regions, provenances and genotypes. The number of ML trees decreased with the number of multiples: ML2 > ML3 > ML4. Among the four species, *A. aulacocarpa* had the highest percentage of ML trees (44.76%) compared to *A. auriculiformis* (31.76%), *A. crassicarpa* (12.33%) and *A. mangium* (11.15%). Provenance from the PNG region also showed a higher number of ML in all classes for all species except for the *A. crassicarpa,* where provenance from the QLD region showed the opposite result. For instance, provenance Arufi E Morehead WP of *A. aulococarpa*, PNG recorded the highest number of ML (64 trees) followed by provenance W Morehead PNG of similar species with a total of 57 ML trees and provenance Mibini of *A. auriculiformis* with 56 trees (Eldoma *et al.* 2015a) (Figure 16).

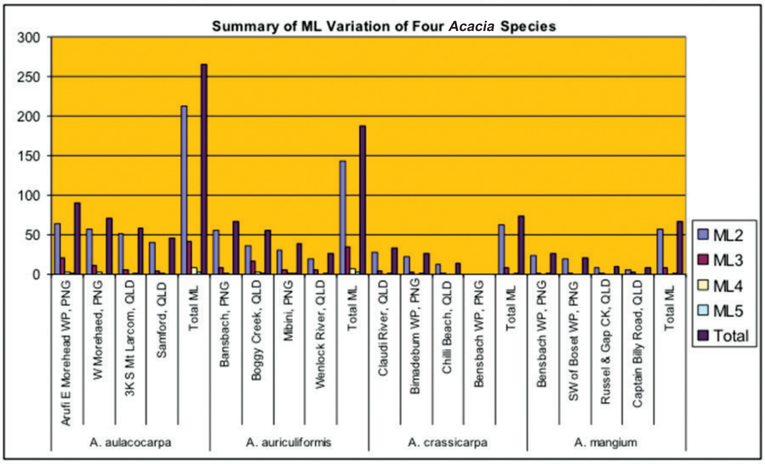

Figure 16 ML variations in four *Acacia* species planted under the same environmental conditions

The results of another study with similar objectives established that the land preparation method by burning could induce ML formation, where the number of ML trees was found to be significantly higher on a burnt site (49.09%) rather than on an unburned site (4.25%). Conversely, *A. mangium* was found to be more responsive in the formation of ML than *A. auriculiformis* on the burnt sites, with values ranging from 66.67% of SE of Daintree (QLD) to 93.66% from Wenlock River (QLD) for *A. mangium* provenances, while it ranged from 6.25% from Wenlock River (QLD) to 20.66% for Mary River (NT) for *A. auriculiformis* (Eldoma *et al*. 2015a) (Table 6). The number of stems per tree ranged between 2 to 5 on the burnt sites while only 2 stems were recorded for the trees on the unburned sites.

Table 6 Comparison of ML (trees/plot) and ML occurrences (%) between the burnt and unburned sites for *A.mangium* and *A.auriculiformis* genotypes

Provenance	ML(trees/plot)		ML(%)	
	Burnt	Unburned	Burnt	Unburned
A. mangium				
Tully Mission Beach (QLD)	12.00	0.50	93.66	1.82
SSO kuranda (QLD)	9.50	0.75	92.98	5.13
Oriomo Province WP (PNG)	11.25	0.75	83.87	4.88
SE Daintree (QLD)	9.50	0.25	66.67	4.00
A. auriculiformis				
Mary River (NT)	3.25	1.25	20.63	8.88
Elizebeth River (NT)	4.50	0.25	16.13	0.00
SSO Fiji (PNG)	3.50	0.75	12.50	7.14
Wenlock River (QLD)	1.50	0.50	6.25	4.26
Combined Average	6.78	0.63	49.09	4.51

If the objective of the plantation is to produce high quality grade timber, then multiple leader trees should be rejected. This suggests that tending operations such as singling is necessary to improve productivity. Results of singling have significantly improved growth in terms of height but not DBH and volume and the effects were evident only after 36 months of being treated. The height of ML trees being singled was recorded at 19.90 m compared to the ML retained / control (17.24 m) and single stem trees (17.07 m) (Figure 17).

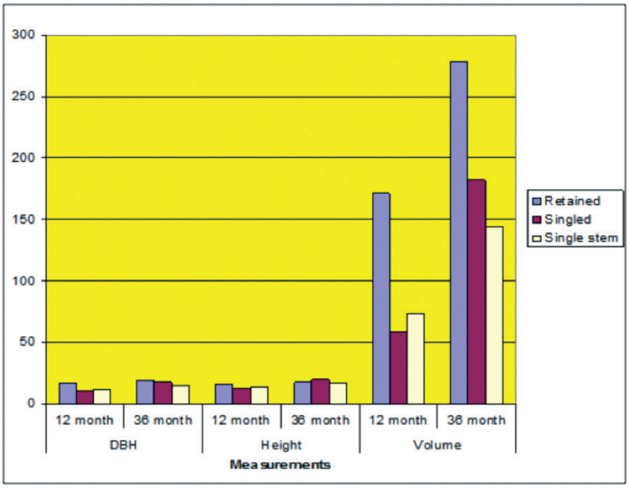

Figure 17 Comparison of DBH, height and volume after 12 and 36 month of singling

Further, evaluation of selected physical and mechanical properties found them to be significantly affected, either by different provenances for *A. mangium* or by different ML classes for *A. crassicarpa* (Table 7).

Table 7 Physical and mechanical properties of *Acacia crassicarpa* and *Acacia mangium*

Species	Source of Variation	Physical			Mechanical	
		Specific Gravity	Radial Shrinkage	Tangential Shrinkage	Static Bending MOE (N/mm^2)	Static Bending MOR (N/mm^2)
		F Value	*F Value*	*F Value*	*F Value*	*F Value*
Acacia crassicarpa	Multiple Leader	367.57*	732.63*	1002.47*	482.02*	630.2*
	Provenance	0.73^{ns}	0.15^{ns}	0.41^{ns}	1.73^{ns}	1.12^{ns}
Acacia mangium	Multiple Leader	0.11^{ns}	0.83^{ns}	0.83^{ns}	0.54^{ns}	0.15^{ns}
	Provenance	10.78*	7.16*	16.85*	16.43*	6.85*

Wood of ML2 (with 2 stems) recorded higher values for SG, MOE and MOR than that for ML3 (with more than 2 stems). ML2 also showed lower shrinkage values compared to ML3 (Nor Aini *et al.* 2013).

It was also found that there were significant differences between species and provenances for biomass production and selected photosynthetic assessment (A_{max} and quantum yield) and wood strength (specific gravity) (Nor Aini *et al.* 2007c, Nor Aini *et al*. 2007d). The relationship between these properties revealed that *A.aulacocarpa* which had high specific gravity had lower photosynthetic efficiency (Sapari *et al*. 2009). (Table 8).

Table 8 Mean values of A_{max}, quantum yield and specific gravity of *A. mangium* and *A. aulacocarpa* provenances with respect to ML formation and provenance

Sources of variation	A_{max} (μmol CO_2 $m^{-2}s^{-1}$)	Quantum Yield (μmol CO_2 $m^{-2}s^{-1}$)	Specific Gravity
A. mangium	**9.6061[a]**	**0.0229292[a]**	**0.6785[b]**
A. mangium ; Captain Billy Road (QLD)	11.155[a]	0.026583[a]	0.7514[ab]
A. mangium ; Bensbach WP (PNG)	10.296[b]	0.025967[a]	0.6444[bcd]
A. mangium ; SW of Boset WP (PNG)	8.728[c]	0.019817[b]	0.7232[ab]
A. mangium ; Russel & Gap CK (QLD)	8.245[c]	0.019350[b]	0.5952[d]
A. aulacocarpa	**6.3988[b]**	**0.0164750[b]**	**0.7339[a]**
A. aulacocarpa ; Samford (QLD)	6.906[d]	0.017500[b]	0.7635[ab]
A. aulacocarpa ; 3K S Mt Larcom (QLD)	6.650[de]	0.016433[b]	0.8044[a]
A. aulacocarpa ; W. Morehead (PNG)	6.049[e]	0.016267[b]	0.6729[bcd]
A. aulacocarpa ; Arufi E. Morehead WP (PNG)	5.990[e]	0.015700[b]	0.6946[bc]

The second component i.e. multi-locational provenance trials of *A. excelsa* were established at three locations, viz: Rantau Panjang (Selangor), Mercang (Terengganu) and Balai Ringin (Sarawak), using 6 seed sources from different parts of Malaysia and Thailand. Concurrently, assessment of genetic variation using both biochemical markers (isozymes) and RAPD, together with morphological variation of these provenances, were conducted to determine the actual variation (intra and inter) (Hazandy *et al.* 2001, Hazandy *et al.* 2008). Growth assessment at 24 months indicated that survival and growth were significantly affected by different locations and provenances. Generally, all provenances performed equally well at Balai Ringin (Sarawak) while growth was rather inconsistent and poor in Mercang (Terengganu) (Table 9).

Table 9 Site ranking based on overall performances of growth parameters

Site	Survival (%)		Height (m)		BD (cm)		DBH (cm)	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Balai Ringin	98.7[a]	96.0[a]	168.2[a]	384.2[a]	-	-	1.1[a]	4.1[a]
Rantau Panjang	91.25[b]	86.45[b]	154.83[b]	259.39[b]	2.54[b]	4.22[b]	1.0[b]	2.66[b]
Merchang	70.0[c]	41.33[c]	57.12[c]	113.69[c]	0.70[c]	1.246[c]	-	0.42[c]

This was due to differences in the physical properties of the locations. Three potential provenances, e.g. Bukit Lagong, Manong, and Semenggok, were found to be stable in all three locations. Further, analysis of morphological and genetic variation revealed that these provenances were closely related. Selection of plus trees from the trials, based on the growth and genetic parameters, were undertaken to secure their valuable genetic resources for micropropagation purposes (Figure 18).

Figure 18 Development of micropropagation techniques utilizing improved genotypes from selected plus trees of some important tree species

In addition, provenance variation of *Shorea leprosula* also revealed significant differences in growth and selected physiological characteristics. Lentang and Sg. Menyala provenances outperformed the others in terms of growth while the Tranum provenance performed the poorest. Similarly, the provenance from Sg. Menyala also showed the best performance in net photosynthetic rate, transpiration and stomatal conductance. Some physiological studies were conducted on other species, viz; *Hopea odorata* (Hazandy *et al*. 2009b) and *Hibiscus cannabinus* (Tahery *et al*. 2011c, Tahery *et al*. 2011d). Provenance variation was also assessed in relation to genetic variation of *Shorea* using the isozyme variation (Nor Aini 1990). Isozyme variation of selected *Shorea* species involving 5 to 16 provenances revealed considerable variations, being coded by 11 to 23 loci from 8 to 12 enzyme systems. Details of the genetic variability in terms of heterozygosity, polymorphic loci and mean allele per locus through isozyme variation *of A. excelsa* and selected *Acacia* species/provenances revealed considerable variation in relation to provenance (Nor Aini 1999, Nor Aini and John 2003, Nor Aini and Wong 2003, Nor Aini *et al.* 2006, Hazandy *et al*. 2008).

In addition, assessment of genetic variation using RAPD was also conducted on selected species. For instance, apparent polymorphism was detected within species for all 20 primers in three *Shorea* species. Four bands were detected, i.e. common, minor, rare polymorphic and unique bands, and a total of 333 bands were identified. The relatively high degree of polymorphism within the species suggests that this species has large effective population sizes and/or large mutation rates due to longer generation time and interspecific divergence at about 1.5 times that of the diversities within species. Interspecific divergence suggested that *S. leprosula* and *S. curtisii* are more closely related to each other than *Shorea acuminate* (Harada *et al*. 1994). In addition, a total of 87 scorable loci were observed using 8 primers in *A.crassicarpa*. PNG provenances also gave higher polymorphism values than QLD provenances of *A. crassicarpa* (John and Nor Aini 2005). Such high variability was consistent with the results of the isozyme analyses (Nor Aini and John 2003). The findings of this study suggested that Papua New Guinea is the center of diversity for the *Acacia* species. These conclusions are based on the results obtained from isozyme interpretations, growth performance, morphological and physiological variations.

The results of the micropropagation studies of the third component indicated that rinsing with commercial Clorox (15%) for at least 15 minutes was effective in producing aseptic *A. crassicarpa* seeds, and that the nodal stem segment obtained from aseptically germinated *A. crassicarpa* seedlings was most appropriate for shoot formation when cultured on a MS medium supplemented with BAP (Griffin *et al.* 1999b). Shoot proliferation was also observed in the same medium with the highest multiplication rate obtained from the second subculture on the medium supplemented with 2.0 mgl^{-1} BAP. Rooting and development of callus were best achieved on a medium supplemented with 2, 4-D after 14 days of in culture incubation (Griffin *et al.* 2014). Micropropagation from marcots and auxiliary buds of *A. auriculiformis* trees of different ages also yielded some promising results although it was more successful when the explants were taken from younger trees. Survival of the plantlets was high when transplanted into an autoclaved mixture of soil, sand and peat (3:3:1) for the *A. crassicarpa* and into shredded coconut husk for the *A. auriculiformis,* during acclimatization (Kamis *et al.* 1998). On the other hand, the micropropagation protocol for *A. excelsa* was developed using the nodal segment. Petiole nodal segments' shoot tips and young produced the highest percentage of shoot formation (93%). The combination of 2.0 mgl^{-1} BAP + 2 mgl^{-1} NAA was found to be optimum for rooting of *in vitro* plantlets with shoot proliferation rate of 2 within 53 days. In addition, the 20 to 25% sterilization method for shoot tip explants yielded 100% aseptic cultures (Juddy *et al.* 1997, Juddy and Nor Aini 1997, Nor Aini *et al.* 1998b, Nor Aini *et al*. 2008).

Results of the macropropagation through rooting of cuttings of these species are summarized in Table 10. Rooting of cuttings was found to be affected by species, age, cutting position, rooting media and hormonal treatment. Study of the copping ability of stumped seedlings of *A. excelsa* examined the effects on stump height while in the rooting of cuttings, the effects of different materials, positions and hormones were examined. Coppicing ability was found to vary with stump heights, i.e. 60 cm > 100 cm > 30 cm.

Table 10 Summary of planting stock production through macropropagation techniques

Species	Provenances	Plant Material	Rooting Medium	IBA Con. (µg)	Rooting %
Hopea ordorata	n/a	Seedlings (3-5 months)	Sand	0-150	83 to 95
Acacia auriculiformis	Papua New Guinea, Queensland	Seedlings (3-5 months)	Sand, Paddy husk	0-150 Seradix 3	50 to 77
Acacia mangium	Papua New Guinea, Queensland	Coppice	Paddy husk	Seradix 3	38.9 to 66.7
Shorea leprosula	Lentang,Sg. Menyala	Seedlings (9-10 months), Coppice	Sand,Paddy husk,Coconut fibre	0-150 Seradix 3	0 to 72
Shorea curtisii	n/a	Seedlings (9months)	Sand,Paddy husk,Coconut fibre	0-150 Seradix 3	4 to 52
Shorea acuminata	Sg. Lalang	Seedlings (18months)	Paddy husk, Coconut fibre	0 – 150 IBA + NAA	58 to 79.5
Shorea parvifolia	Selaru	Seedlings (18months)	Paddy husk, Coconut fibre	0 – 150 IBA + NAA	62 to 70.8
Azadirachta excelsa	Pasir Mas	Copping material (3 monts)	Sand	0-30 Seradix 2	13.3 to 36.7

However, 100 cm stumps produced more vigorous survival and rooting percentages. Cuttings from coppice shoots survived and rooted better than those from seedlings. Further, both positions and hormonal treatments significantly affected the survival and rooting percentages. Terminal cutting position and hormonal treatment of Seradix 2 (0.3% IBA) recorded the highest rooting ability.

CONCLUSION

A particular trait for a straight or (un)straight form is influenced by genetic and environmental factors. Environment and site conditions play a vital role in determining the form and growth habit of a tree. The use of selected genotypes from various provenance and progeny of a species is very important to maximize utilization and to increase the productivity of a plantation. The (un)straight trait which is a crooked form or a formation of multiple leaders might be a potential problem if the establishment of the forest plantation is only meant for the production of high quality timber. On the other hand, the (un)straight form can be an advantage for the purpose of urban forestry landscaping where aesthetic values are appreciated or sought after.

For plantation forestry to be successful and practiced widely, the private sector must play a greater direct role by managing plantations or indirectly by providing financial support for the implementation of plantation forestry. In fact, many factors can contribute to such outcomes but high productivity and high value products are the two key elements. The genetically improved materials selected in this study combined with appropriate propagation techniques and good silvicultural practices can ensure improvement in the productivity and product quality of plantation forests.

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BIOGRAPHY

Nor Aini Ab Shukor was born on 3rd June 1960 in Pontian Kecil, Johor. She started her primary education at Tengku Mahmud Iskandar (1) School before continuing her secondary education at Sekolah Menengah Sains Johor. She attained her B.Sc (Hons) in Genetics from the Universiti of Malaya in 1984 and then joined the Faculty of Forestry, Universiti Putra (then Pertanian) Malaysia. Upon securing a scholarship from the Public Services Department, Malaysia and the Commonwealth Academic Staff Scholarship (AACU), she pursued further studies and graduated with an M.Sc and Ph.D in Genetics from the University of Wales, United Kingdom in 1985 and 1988, respectively. She was promoted to Associate Professor in 1996 and Professor in 2006. She was entrusted with managing a number of courses and teaches courses on Tree Improvement, Advanced Tree Improvement, Seed Technology, Tree Physiology, Plantation Silviculture and Quantitative Methods in Forestry.

Her range of responsibilities also involves administrative work. Currently, Nor Aini is the Deputy Dean of the School of Graduate Studies at UPM. She has served as the Deputy Dean (Research and Graduate Studies), Faculty of Forestry in 1999, Graduate Coordinator of Asia-Pacific Association of Forestry Research Institutions (APAFRI) for the Applied Research Outreach (ARO) Programme and International Forestry Students' Association in 2002 and 2005 respectively, Head of the Laboratory of Sustainable Bio-resource Management, Institute of Tropical Forestry and Forest Products (INTROP) in 2006 and was visiting professor at the Department of Plant Science, Imperial College, London, United Kingdom from 2010-2012. Additionally, she was also the secretary for the International Commonwealth Forestry Conference (1992) and International Conference of Medicinal Plants (2005) among others.

Her active participation and devoted commitment to academia, teaching and research have earned Nor Aini some awards acknowledging her excellence in service, such as
Excellence Service Awards in UPM and in research, such as, the Commonwealth and British Chevening Fellowship from the United Kingdom and the Monbusho and JSPS Fellowship from Japan. To date, Nor Aini has supervised more than 65 undergraduates, 26 Masters and 16 PhD students with 4 ongoing Masters and 4 ongoing PhD students.

Her research initiative reached its apogee in 1989 when she was first involved in the multipurpose tree species (MPTS) research network project which was sponsored by the Winrock International and involved partnerships with the Asian-Pacific countries, part of the North-Western Asian countries and Africa. The project was such a tremendous success that it served as an exemplar to attract the interest of many funding agencies such as IRPA, CIDA, EARO, IDRC and CFC to support the project and to generate extra funds to run similar projects in the country, pertaining to tree improvement research.

Additionally, Nor Aini has been involved in the screening of suitable genotypes from provenances and progeny trials of some important commercial MPTS such as *Acacia*, *Shorea* and *Eucalyptus* species. She ran a joint project under the JSPS-LIPI Core University Programme and an EU project on Tissue Culture and Molecular Breeding of Fast Growing Tropical Tree Species where the output was utilized for further propagation and expansion using both conventional and biotechnology methods.

To date, she has published more than 90 journal articles, more than 100 national and international proceedings, chapters in books and reports. Her expertise in Tree Improvement has been recognized locally and internationally with her being invited as a visiting lecturer, guest speaker, exhibitor, committee member, secretariat member, chairperson and organizer in many conferences, seminars and workshops, besides presenting and reviewing scientific and technical papers and research proposals.

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LIST OF INAUGURAL LECTURES

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2. Prof. Ir. Abang Abdullah Abang Ali
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3. Prof. Dr. Abdul Rahman Abdul Razak
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4. Prof. Dr. Mohamed Suleiman
   Numerical Solution of Ordinary Differential Equations: A Historical Perspective
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5. Prof. Dr. Mohd. Ariff Hussein
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6. Prof. Dr. Mohd. Ismail Ahmad
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7. Prof. Dr. Mohamed Mahyuddin Mohd. Dahan
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   20 April 1994

8. Prof. Dr. Ruth Kiew
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   11 May 1994

9. Prof. Ir. Dr. Mohd. Zohadie Bardaie
   Engineering Technological Developments Propelling Agriculture into the 21st Century
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10. Prof. Dr. Shamsuddin Jusop
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11. Prof. Dr. Abdul Salam Abdullah
    Natural Toxicants Affecting Animal Health and Production
    29 June 1994

12. Prof. Dr. Mohd. Yusof Hussein
    Pest Control: A Challenge in Applied Ecology
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13. Prof. Dr. Kapt. Mohd. Ibrahim Haji Mohamed
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14. Prof. Dr. Hj. Amat Juhari Moain
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15. Prof. Dr. Law Ah Theem
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16. Prof. Dr. Md. Nordin Hj. Lajis
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17. Prof. Dr. Sheikh Omar Abdul Rahman
    Health, Disease and Death in Creatures Great and Small
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18. Prof. Dr. Mohamed Shariff Mohamed Din
Fish Health: An Odyssey through the Asia - Pacific Region
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19. Prof. Dr. Tengku Azmi Tengku Ibrahim
Chromosome Distribution and Production Performance of Water Buffaloes
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20. Prof. Dr. Abdul Hamid Mahmood
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21. Prof. Dr. Rahim Md. Sail
Extension Education for Industrialising Malaysia: Trends, Priorities and Emerging Issues
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The Diminishing Tropical Rain Forest: Causes, Symptoms and Cure
19 August 1995

23. Prof. Dr. Ang Kok Jee
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24. Prof. Dr. Sharifuddin Haji Abdul Hamid
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Sustained Growth and Sustainable Development: Is there a Trade-Off 1 or Malaysia
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47. Prof. Dr. Muhamad Awang
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60. Prof. Dr. Wan Md. Zin Wan Yunus
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