Gradual transformation of Forest Plantations into Close-to-Nature Forests in NE Vietnam

Dissertation

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Abbreviations

MARD	Ministry of Agricultural and Rural Development (Vietnam)
MOF	Ministry of Forestry (Viet Nam)
DARD	Department of Agricultural and Rural Development (Vietnam)
FAO	Food Agricultural Organisation
FIPI	Forest Inventory Planning Institute (Vietnam)
KfW	Kreditanstalt für Wiederaufbau (Germany)
FSIV	Forest Science Institute of Vietnam (Vietnam)
MAI	Mean Annual Increment (m^3)*
drc	Diameter at Root Collar**
CAI	Current Annual Increment (m^3)*
dbh	Diameter at breast height (cm)*
NIAPP	National Institute of Agriculture Planning and Projection (Vietnam)
PAM	Programme Alimentaire Mondial
PTCs	Potential Crop Trees
BMZ	Ministry for Economic Cooperation and Development (Germany)
JICA	Japan International Cooperation Agency
STRAP	Strengthening Re-Afforestation Programs
IUCN	International Union for Conservation of Nature
UNDP	United Nations Development Programme
WWF	World Wild Foundation
MBFP	Management Board for Forestry Projects (Vietnam)
a.s.l	Above see level
*G*ha	Basal area (m^3)*

ha	Hectare
*N*ha	Number of trees per hectare*
h	Total height (m)*
CW	Crown width*
Et	The time of planting
IVI	Importance Value Index
NEVFSPC	North Eastern Vietnam Forest Scientific and Productions Centre
5MHRP	Five Million Hectares Reforestation Programme
CAF	Chinese Academy of Forestry
NEVFSPC	North Eastern Vietnam Forest Scientific and Productions Centre
hh	Households
FRA	Forest Resources Assessments
FUV	Forestry University of Vietnam

* According to the Internatinonal Union of Forestry Research Organizations (IUFRO) standard cited by (Laar and Akca 2007)

** According to (Chojnacky and Rogers 1999)

1 Introduction

1.1 Forests and Forestry in Vietnam

According to various documents from the IUCN, UNDP, and WWF (1993), about 20 million hectares of forest worldwide disappear every year, 50 % of which is destroyed by shifting cultivation, 23 % by forest fire, and 5 - 7 % through illegal exploitation. Tropical forests comprise nearly 50 % of the world's forest. In recent years, this forest has disappeared at a rate of about 1,300,000 hectares per year (FAO 2001). Significantly, a great proportion of this deforestation occurs in developing countries, particularly those in tropical Asia and Central America, both of which demonstrate the greatest amount of forest loss at an annual rate of more than 1 %. The main factors contributing to the degradation of the forest ecosystem on these continents are as stated above, with the addition of illegal logging, and over-harvesting (Hoang 2005; Lee *et al.* 2006).

In Vietnam, the forest cover years declined significantly during the second half of the last centrury. In 1945, 43% of Vietnam was covered by forest, amounting to approximately 14.2 million hectares (MARD 2004; FAO 2011), but this figure dropped to 30 % by 1976 (Thao 2011) and to 28% by 1996 (FIPI 1997; Trung 1998; FAO 2011). The primary causes of this decrease were over-exploitation of forest resources, shifting cultivation (WCMC 1994; Hoang 2005; Thao 2011), conversion of natural forest to coffee and rubber plantations (Hoang 2005; Thao 2011), grazing, and illegal logging (WCMC 1994). During the war between Vietnam and United States of America (1956-1975), about two million hectares of forest were destroyed due to bombardment with defoliant chemicals (Hoang 2005; Hung 2008).

Since 1992, the Vietnamese Government has begun enacting numerous policies, programmes, and projects, with the intention of accelerating forest rehabilitation. "PAM," with a total of seven projects from 1977 – 2000 (MARD 2004), the "327 Programme" (1992 – 1998), and the "Five Million Hectare Reforestation Programme (5MHRP)" (1998 – 2010) are examples of the various initatives the Government has undertaken. The "5MHRP" has been particularly successful. The stated goal was to reach a forest cover rate of 43 % (14 million ha) (MARD 2004), and as a result of this programme, Vietnam achieved 12.6 million hectares of forests (36.7 %) by 2005, 3.3 million hectares more than that had existed in 1996 (Bao 2005; Hung 2008). By the end of 2010, the total forest area of Vietnam (including natural forest and plantation area) was at 13.4 million hectares, accounting for 39.5 % of national forest cover. One year later, the 5MHRP established a total of 4.7 million hectares of forest plantation, accounting for 93.5 % of the defined target of five million hectares (Anonymous 2011a). Today, this number has reached 10.3 million hectares of natural forest and 3.08 million hectares of plantation forest (MARD 2011).

Rationale

In 2010, the worldwide scale forest plantation covered 264 million hectares (FAO 2011). In comparison to recorded data from 1995, this represents a significant increase of 124 million hectares. Globally, the reported new annual planting rate is 4.5 million hectares, 89 % of which is new plantations in Asia and South America (Montagnini and Jordan 2005).

In 2008, the final report of field inventory of MARD revealed that the area of *Pinus massoniana* plantations in Vietnam was at 327,200 hectares, while that of *Acacia* plantations was at about 400,000 hectares. In recent years, both *Pinus* and *Acacia* have been the main species selected for “5MHRP” in Vietnam. Because most of the areas selected for reforestation suffered from a long period of shifting cultivation by local famers, the soil was degraded due to nutrient leaching. The sites were thus unsuitable for the planting of indigenous species, and could only be adapted to species of *Pinus* and *Acacia* (MARD 1995a; 1996a). In term of economics, a plenty of Vietnamese studies have proven short rotation to be among the many advantages of pure plantations with exotic tree species (MARD 1996b). With these rapidly-growing species, financial returns are more easily recouped (Lamb 2011). Furthermore, these species grow well in dry, acidic, and poor soils (FIPI 1996; Lamb 2011), and can enhance the speed of the regreening. Seeds are available from previous tree-breeding programmes and established nursery/plantation management systems make them easily match (Lamb 2011). Forest plantation improves degraded lands by stabilizing the soil, the soil nutrient status, and increasing the soil organic matter through the enhancement of (above-ground) litter production (Jordan and Farnworth 1982; Ohta 1990; Lugo 1992; Parrotta 1992; Lugo *et al.* 1993; Cruz *et al.* 1994; Fisher 1995; Parrotta 1995; Michelsen 1996). Additionally, such plantations can also improve the micro-climate (Ohta 1990; Parrotta 1992; Cruz *et al.* 1994; Fisher 1995), and may promote the natural regeneration process of native woody species, particularly on sites where seed banks of native forest species are lacking. These are in turn likely to increase the chances of germination and establishment, normally difficult on highly degraded sites (Parrotta 1992; Kuusipalo *et al.* 1995; Parrotta *et al.* 1997; Senbeta and Teketay 2001; Thang 2003; Do and Van 2009).

Pure plantations made up of *Pinus* and *Acacia* species have some disadvantages, including diseases and forest fire. Based on recorded data, *Pinus* insects have appeared in lage scale within the last few years (2008, 2009, and 2010), damaging about 2,000 hectares of plantation; current documentation from the Ministry of Vietnam Agricultural and Rural Development (MARD) denmonstrated that forest fires were 880 times in 2010 (Anonymous 2010), and damaged a total of 2,660 hectares (MARD 2011). Between January and March of 2011, forest fires in the Kon Tum Province damaged 280 hectares (Anonymous 2011b). Comparitively, about 10,000 hectares of a *Pinus massoniana* plantation in the Lang Son Province were damaged by insects in 2009 (Chien 2009). In May and June 2011, a total of 2,000 hectares of a *Pinus* plantation in the Nghe An Province were infested by insects (Dung 2011).

Numerous studies across the world have shown that mixed forest plantation has more advantages than pure counterparts-particularly when they also contain indigenous broad-leaf species (Piotto *et al.* 2004; Montagnini and Jordan 2005; Kelty 2006). They increase stand productivity, improve the nutrition status, and resist pest diseases, as well as generate various important financial benefits (Lamb 2011). Two mechanisms by which mixtures may reduce the risk of pest damage are: (1) mixtures may dilute the host concentration for pest organisms, thereby impairing the ability of the pest to find the host, and (2) mixtures may provide more diverse habitats that tend to support higher populations of the natural enemies of the pest species (Watt 1992). Moreover, mixed plantations yield more diverse forest products than monoculture stands, thus helping to diminish the farmer's risks in unstable markets (Piotto *et al.* 2004; Kelty 2006). Indeed, farmers may prefer mixed plantations in order to diversify their investment, and use them as a potential safeguard against pests and diseases (Piotto *et al.* 2004). Furthermore, natural regeneration in the understory is far more successful in mixed plantations than in pure plantations or abandoned pastures (Carnevale and Montagnini 2002; Cusack and Montagnini 2004). Mixed plantations also lend good results in terms of the accumulation of above-ground biomass and carbon sequestration (Montagnini and Porras 1998; Montagnini *et al.* 2005). Mixed plantations with native species have social and economic functions, provide forest products, contribute to the rehabilitation of degraded areas, promote atmospheric carbon sequestration, and restore biodiversity.

To maintain and promote the important roles of forests, one must establish mixed plantation forests with different ages of indigenous species and high economic values, in order to both enrich the usage of forest in the economy and suitably maintain the ecosystem. Mixed plantation brings both immediate and long-term benefits to the participating farm-households, decreases the risk of forest fires, controls insects and disease, improves the ecology, and maintains protective functions of the forest. Thus, planting some indigenous species under pure forest plantation close to the nature forest is both urgent and necessary.

Definitions

To classify the topics, a brief definition follows:

Plantation Forest: Forest stands established by planting and/or seedling in the process of afforestation or reforestation. They are of either introduced species (all planted stands) or intensively managed stands of indigenous species, and must meet all the following criteria: one or two species at planting, even-aged class, and regular spacing (FRA 2000; FAO 2010; Biodiversity 2012). According to FAO, forest plantation consist of introduced or indigenonous species which meet a minimum area requirement of 0.5 hectares, a tree crown cover of at least 10 % of the land surface, and a total height of adult trees at or above five metres (FAO 2000).

Afforestation: Conversion from other land uses into forest, or the increase of canopy cover to above the 10 % threshold (FRA 2000). Establishment of forest through planting and/or deliberate seedings on land that was not previously classified as forest. Implies a transformation from non-forest to forest (FAO 2010; Biodiversity 2012).

Reforestation: Re-establishment of forest formations after temporary conditions (lasting fewer than ten years), with less than 10 % canopy cover due to human-induced or natural perturbations (FRA 2000). Re-establishment of forest through planting and/or deliberate seeding on land classified as forest (FAO 2010). Establishment of forest plantation on temporarily unstocked lands that are considered forest (Biodiversity 2012).

Natural forest: Forests composed of indigenous trees that regenerated naturally, which can included both spontaneous and assessed natural genenerations (FRA 2000; Biodiversity 2012).

Pure (or Monoculture) forest plantation: The planting of a single species carried out at one specific time period. The species may be indigenous or exotic, and is commonly established at densities of around 1,100 trees per hectare (Lamb 2011).

Natural regeneration: The re-establishment of native trees and other plants by self-sown seed or vegetative regrowth (Lamb 2011). Forests established by natural regeneration without deliberate assisstance from man, which includes virgin forests and those regenerated by natural means (FRA 2000). Predominantly composed of trees established through natural regeneration (FAO 2010). Natural succession of forest on temporarily unstocked lands that are considered as forest (Biodiversity 2012)

Regeneration: The renewal of a tree crop through either natural (seeds on site from adjacent stands or deposited by wind, birds, or animals) or artifical means (by planting seedling or direct seedling) (Francis 2006). The regeneration of the ecosysterm or the rehabilitation of forest components (Lan 1991).

Indegenious tree species: Naturally distributed species in a local area or country, including exotic species which have been planted for a considerable amount of time and that have high adaptive ability in the local environment (Duc 2006). A native species is one which naturally exists at a given location or in a particular ecosystem, i.e., has not been brought there by humans (Biodiversity 2012).

Exotic species: An alien species, sub-species, or member of a lower taxon that has been introduced outside its normal past and present distribution; includes the gametes, seeds, propagules, or any other part of such species that may survive and subsequently reproduce (Biodiversity 2012).

Seedling and sapling: ”Seedlings” are defined as trees < 0.5 m tall, and ”saplings” as trees ≥ 0.5 m tall but <10 cm diameter at breast height (*dbh*) (Carter and Fredericksen 2007).

Potential Crop Trees (PCTs): Regenerated trees taller than shurbs, and ground cover layers with normal or good qualities, and stand higher than 30 cm (Thuong 2003).

Associated tree: Trees are living at the same time and place. Can support each other in their growth and development (MARD 1996),

1.2 State of knowledge of indigenous tree species

1.2.1 World-wide

Over the past few years, indigenous tree species have been studied, trialed, and successfully planted in different regions worldwide. Among the variety of planted species, those belonging to genus *Paulownia* have drawn much attention from many Asian countries and others all over the world. According to Tran Quang Viet (2001), the genus *Paulownia* was studied during the Green Revolution in China and has been developed since the 1960s. The Chinese Academy of Forestry (CAF) has conducted a systematic research of the classification, ecological features, distribution, planting techniques, and uses of species in the genus *Paulownia*.

Since 1950s, Lee *et al* (2005) studied the succession of natural woody plants under different types of closed-canopy plantations (*Acacia confuse, Lophostemon confertus, Melaleuca quinquenervia,* and mixed-plantings of *Acacia auriculiformis, A.mangium, Eucalytus citriodora, Cunninghamia lanceolata,* etc.) and natural forest in the Central New Territories of Hong Kong. The results indicated that species composition of the understory were significantly different among plantation types. The colonization of native tree species was poor on sites isolated from natural seed sources. The understories of plantations were generally dominated by a few species of bird-dispersed shrubs. The research suggested that enrichment planting with poorly dispersed shade-tolerant native tree species is needed in order to facilitate their natural regeneration. In addition to apply suitable management measures like the thinning of exotic trees and the planting of both shade-tolerant native species (such as many of Fagaceae) and native tree species with fleshy fruits for attracting seed dispersers, other management measures are needed to rehabilitate the understory plant community, as well as to speed up natural succession.

Some studies examined the effects of removing *Acacia mangium* in the overstory layer on the growth of underplanted *Anisopera marginata* saplings in South-Kalimantan, Indonesia (Riikka 1998). At the time of the overstory´s removal, the *Acacia magium* trees were eighty months old (mean height 21 m and *dbh* 20 cm), and the underplanted *Anisopera marginata* saplings were sixty-eight months old (mean height 4.2 m and *dbh* 3.1 cm). The result demonstrated that the Mean Annual Increment (*MAI*) of height and *dbh* of *Anisopera marginata* were higher in canopy gaps than under a closed canopies twenty-two months after treatment.

Another research project in Malaysia (Anonymous 1999) examined mixed plantations under canopies of natural forest and *Acacia mangium* plantations of ten to fifteen years old and two to three years old stands. A total of twenty-three indigenous species were planted on 30 m strips in the natural forest, while only fourteen indigenous tree species were planted in two trial blocks under the *Acacia mangium* canopy. Three planting methods were applied in “Block A,” each one involving lines of indigenous trees. These methods were (i) the creation of a 10 m strip planted with three lines, (ii) the creation of a 20 m strip planted with seven lines, and (iii) a 40 m strip planted with fifteen lines.

Three planting methods were also applied to “Block B”: (1) the removal of one line of *Acacia* to plant one line of indigenous trees, (2) the removal of two lines of *Acacia* to plant two lines of indigenous trees, and (3) the removal of four lines of *Acacia* to plant four lines of indigenous trees. The results denmonstrated that three of the fourteen indigenous species planted in “Block A,” including *Shorea roxburrghii, Shorea ovalifolia,* and *Shorea leprosula,* developed well and had the highest height and diameter. There was no significant difference in survival rates, however, between species planted in the 10 and 40 m strips - both had good height and growth ability, while those planted in the 20m strip did not grow to be as tall. “Block B” retained a high survival rate with a considerable height development in species planted in one line, and a diameter development in species planted in two and four lines.

Piotto *et al.* (2004) experimented with the growth and development of thirteen native species in pure and mixed plantations in regards to *Tectona grandis*, an exotic species broadly planted in the dry conditions of Costa Rica. The results showed that most of the native species grew better in mixed plots, and the *Tectona grandis* plantation seemed to be well-adapted to the region.

Senbeta and Teketay (2001) studied a total of five exotic species in Central Ethiopia (*Cupressus lusitanica, Eucalytus globulus, Pinus patula, P.radiata,* and *Juniperus procera*) in monoculture plantations. The age of the plantations varied between fourteen and forty-two years. The results indicated that forest plantation can be considered a useful tool in fostering the natural regeneration of native woody species, especially on sites where the soil seed banks of native species are lacking. They enhance the process of forest succession over time by attracting seed dispersal agents and providing a nurse effect for colonizing native species. As a result, plantations can enhance the plant diversity of indigenous species. A total of thirty-seven indigenous woody species were naturally regenerated beneath all the plantation stands, with densities ranging between 1,630 and 18,270 individuals per hectare. The author recommend carrying out more research in order to better understand the successional processes within plantations, including seed dynamics (i.e seed dispersal, germination in the field, seed predation) and seedling establishment/growth.

In the 1980s, Kelty (2006) replicated plots of mixtures and monocultures on the same site. The research found higher stand-level productivity in mixtures with two kinds of species interactions: (1) complementary resource use between species, arising from the development of a stratified canopy (and possibly root stratification); (2) a facilitative improvement in the nutrition of a valuable timber species growing in the mixture with a nitrogen-fixing species (but only if combined with complementary resource use as well). These mixtures improve the economic return through greater individual tree growth rates and the provision of multiple commercial or subsistence products. More complex plantation mixtures of five to seventy species have been used for the ecological restoration of degraded land. The large numbers of species of different successional stages are combined to reduce the need for a series of sequential plantings.

1.2.2 Vietnam

Indigenous trees species for the "Protection Forest Programme"

Over the past few years, many studies of indigenous tree species have been implemented in order to support afforestation in Vietnam, with some outstanding studies as follows:

In researching the "Forest Rehabilitation Programme" of Hieu River, Nghe An Province between 1981 and 1985, Nguyen Ba Chat (1995b) experimented with a mixed plantation consisting of *Chukrasia tabularis* and other broad-leaved indigenous species, including *Peltophorum pterocarpum, Michelia sp, Evodia bodinieri,* and *Gmelina arborea.* The goal was to create a proper structure. The careful supervision of the mixed plantation over ten years demonstrated that *Chukrasia tabularis* developed better when planted in the mixed plantation as opposed to the pure one. Mixed plantations of *Chukrasia tabularis* with the use of natural regenerated vegetation proved to have many advantages concerning growth and land recovery. In 1997, Nguyen Ba Chat (1995a) additionally studied and developed the technical guidelines of indigenous species for the "327 plantation Programme." The research found a total of 70 species, and developed a technical guideline for planting twenty, including *Chukrasia tabularis, Cassia siamea, Canarium album, Tectona grandis, Dipterocarpus alatus,* etc.

Another research of indigenous species for the "Protection Forest Programme" of Da River, Lam Phuc Co (1995), selected three indigenous species (*Fokienia hodginsii, Altingia chinensis,* and *Michelia mediocris)* or enrichment planting under the forest canopy and in strips. The results indicated that the growth rate and development of the species in the strips were better than those planted under the forest canopies.

In a study of the ecological features of *Erythrophloeum fordii*, Phung Ngoc Lan (1994) confirmed that *Erythrophloeum fordii* is widely distributed and found in almost all provinces of North Vietnam (from the Hai Van mountain pass further north) at an elevation under 500 m a.s.l. It is suitable to grow on low mountains with an average slope of less than 20°, or at the mid-mountain and foothills.

According to the results of studies on the scientific basis for indigenous species selection in the "Protection Forest Programme" Tran Xuan Thiep (1997), there are two methods to select indigenous species for afforestation: experimentation and trials (semi-production) before conducting afforestation, and consulting with the local people for trial planting or implementing technical procedures. However, Nguyen Hoang Nghia´s research results (1997) indicate a lack of awareness of specific features of indigenous species, such as micro-climate, site conditions, soil, light at different stages of the trees, the relationship among species in the plant communities, natural regeneration ability, etc. Therefore, it is difficult to plant indigenous species at a large scale.

Overall, the planting of indigenous tree species is right-oriented and scientifically based; however, each indigenous species requires a different living environment, along with assorted techniques of planting and tending. Therefore, a study of the suitable technical measures of each kind of indigenous species is required and strongly recommend.

Indigenous species for afforestation and enrichment planting

Luu Pham Hoanh *et al* (1960) conducted trial research on enrichment planting with indigenous tree species such as *Erythrophloeum fordii*, *Dipterocarpus retusus*, *Ormosia balansa,* and *Endospermum chinense*. Methods of both clear cutting and planting trips were applied. The results indicate that the growth rate and development of *Erythrophloeum fordii* and *Dipterocarpus retusus* could be better in trees planted in the strips as opposed to in clear cutting and under forest canopies.

In 1988, *Cinnamomum obtusifolium* was planted in degraded forests in the Tram Lap Forest Enterprise, Kbang District, Gia Lai Province (FSIV 2000). A planting strip 5 meters wide was created, and the remaining strips were divided up to each be 10 meters wide. All shrubs and ground vegetation in the planting strips were removed. Seedlings of 30-50 cm height were used for planting, with a spacing of 2 x 2 m. The survival rate one year after planting was 85 %, the mean diameter was 3.9 cm, and the mean height was 4.38 m. However, the survival rate rapidly decreased in 2000 (to 65 %), and there were strong differences in diameter and height between trees, only 30 % of which had mean diameter and height of 12 cm and 9 m respectively. 70 % of the trees grew slowly in comparision with the shrubs and ground vegetation in the remaining strips. Consequently, silvicultural measures should be applied in an appropriate way to create suitable coverage for the optimal growth of *Cinnamomum obtusifolium.*

Trieu Van Hung (1993) studied the ecological features of *Canarium album* and *Peltophorum pterocarpum,* and indicated that in natural forest, *Canarium album* accounts for only 3.9 % in composition of, and 6.8 % in frequency in appearance in sample plots. The abundance of *Canarium album* in the $IIIA_1$[1] forest is higher than in the $IIIA_2$ forest. In the natual forest, *Canarium album* is often found with other species, like *Machilus odoratissima, Castanopsis sp, Peltophorum pterocarpum, Trema orientalis, Liquidambar formosana, Melia azedarach, Choerospondias axillaris,* and *Schima wallichii.*

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[1] Forest classification of Vietnam (MARD 1984): the category $IIIA_1$ has, as a result of over-exploitation and high-intensity selective logging, an estimated timber volume of 50 - 80 m^3/ha. Timber volume for the category $IIIA_2$ is estimated at 80 - 120 m^3/ha, and for $IIIA_3$ approximately 120 - 200 m^3/ha.

Research of the enrichment planting of *Peltophorum pterocarpum* in strips in the degraded forest of Nghia Dan District, Nghe An Province (FSIV 2000), revealed that the survival rate one year after planting had reached 90 %. The trees grew well in both diameter and height. The good - quality trees occupied 60 % of the stand, and had long and straight stems. However, twenty years after planting, the growth rate had slowed down with the strong development of the branches. In another study conducted in Cau Hai, Phu Tho (FSIV 2000), *Peltophorum pterocarpum* was also planted in strips. Two metre lines were created for the plantation of six-month-old contained seedlings. After being planted for three years, the survival rate was approximately 90 %, with a mean growth of 2.3 cm (diameter) and 2.0 m (height) per year. However, the growth rate began slowing down in the fourth year after plantation. Regenerated species available in the remaining strips grew at a high rate and grew taller than the *Peltophorum pterocarpum* planted in the strips. Between the ages of six and seven, the growth rate of *Peltophorum pterocarpum* was dramatically reduced due to competition by species in the remaining strips for domination of the canopy. *Peltophorum pterocarpum* is a light-demanding species, and should thus not be used for enrichment planting in strips where vegetation develops at an extremely high rate.

The results of the research prove that the growth rate of indigenous species supports the "Forest Preservation and Development Programme" in Cau Hai, Phu Tho. Vi Hong Khanh (2003) concluded that the survival rate and growth speed of *Erythrophloeum fordii* was higher than that of other species. Among the thirty-four indigenous species studied, six (*Erythrophloeum fordii, Cinnamomum obtusifolium, Pygeum arboretum*, *Castanopsis cerebrina*, *Terminalia chebula*, and *Michelia mediocris)* were selected for the "Forest Preservation and Development Programme," had high rates of growth and development, and were disease-free.

Indigenous species under a plantation canopy

In addition to the studies of the basis for species selection and enrichment planting in Vietnam, there are some studies on the planting of indigenous species under plantation canopies. The findings are as follows:

Research conducted by Tran Nguyen Giang (1996) on the planting of ten indigenous species under the canopy of *Acacia auriculiformis* and *Acacia mangium* plantations in Cat Ba National Park, Hai Phong Province, revealed that one year after planting, the indigenous species seemed to be well-adapted and had a solid growth rate. However, the survey results in 1998 showed that the indigenous species planted under the canopy of *Acacia auriculiformis* plantations had a high rate of survival and development, compared to the low rates experienced by those species planted under *Acacia mangium*. According to the research, *Acacia mangium*´s high demand for water was the main reason for the frequent dryness of the soil, leading to the poor growth of the indigenous species.

In 1998, Hoang Vu Tho (1998) studied the effects of ecological factors on the development of a five year-old *Erythrophloeum fordii* planted under a plantation canopy in Xuan Mai – Ha Noi. The study indicated that *Erythrophloeum fordii* showed the best development under canopy closures of 0.3 – 0.4.

A botanical garden was established at the Forestry University in Xuan Mai, Chuong My, Ha Noi, which aimed to collect nearly three hundred indigenous tree species planted under the canopy of *Pinus massoniana* and *Acacia mangium* plantations. As a result of research, Pham Xuan Hoan (2002) demonstrated that some species were found to be suitable for the planting under a forest canopy, among them *Fernandoa brilletii*, *Knema pierrei*, *Garcinia cowa*, *Cinnamomum inners*, and *Cinnamomum camphora*. Futher, the results on the micro-climate conditions under the plantation canopies in Cat Ba National Park in Hai Phong Province, Pham Xuan Hoan (2002), concluded that some of the indigenous species planted under the plantation canopy were well-developed, especially those planted under *Pinus massoniana* and *Acacia auriculiformis* canopies. He also revealed that the closed-canopy plantation and intensity of light were among the factors with significant impact on the growth of indigenous species.

The results of the studies from Hoang Van Thang in Ngoc Lac, Thanh Hoa province and Cau Hai, Phu Tho province (2003) found twelve to twenty-two natural regenerated broad-leaved species under the canopy of fifteen year old *Dendrocalamus membranceus* plantations, eight of which are of high economic value, with a density from 220 - 260 trees/ha and a mean height of 2 m to 2.8 m.

After researching the physiological and ecological characteristics of ten indigenous species planted under the canopies of *Pinus massoniana* and *Acacia auriculiformis* plantations, the North-east Vietnam Forest Scientific and Productions Centre (NEVFSPC) (Hien 2004) indicated that only five of the ten species (*Erythrophleoum fordii*, *Peltophorum pterocarpum*, *Ormosia pinnata*, *Castanopsis boisii*, and *Cinnamomum iners*) had high survival rates and very good growth/development. Of these, *Erythrophleoum fordii* had the highest survival, growth, and development rates.

A study on the influence of ecological factors on the growth and development of indigenous species planted under a canopy of *Acacia auriculiformis* plantations north of Hai Van Pass, Pham Thanh Tung (2006), revealed that four species developed well, namely, *Tarrietia javannica*, *Dipterocarpus alatus*, *Parashorea chinensis*, and *Hopea odorata*. Indigenous species planted under this plantation canopy were directly affected by six surrounding trees.

According to the research on the natural regeneration of indigenous species under a plantation canopy and on bare land in the Nam Lau commune in Son La province (Do and Van 2009), it was concluded that the *Acacia* plantation plays a more important role that *Eucalytus* or bare land in promoting the natural regeneration of indigenous species. Among genus *Acacia*, *Acacia auriculiformis* played the largest role. Up to twenty-two indigenous species appeared under the canopy of *Acacia auriculiformis* plantations with a density of 860 trees/hectare, while only twelve species appeared under the canopy of *Eucalytus* plantations with a density of 467 trees/hectare. Some high economic value species were observed under a plantation canopy of *Canarium tramdenum*. Indeed, the density of the plantations has a significant impact on the regeneration of indigenous species under plantation canopy, whereby a density of 1,660 trees/hectare is considered optimal, as the site conditions are better for the germination and development of indigenous seedlings.

Numerous studies have been conducted in the area of natural regeneration under plantation canopies (Senbeta and Teketay 2001; Thang 2003; Lee *et al.* 2005; Kelty 2006; Do and Van 2009). Most of these studies have confirmed that such plantations can be useful in fostering the natural regeneration of native woody species, particularly on sites where soil seed banks of native species are lacking (Chat 1995b; Senbeta and Teketay 2001; Thang 2003; Lee *et al.* 2005; Do and Van 2009). Native woody plant colonization is rich on a site closed to a natural seed source, and most native species grow better in the mixed plots (Senbeta and Teketay 2001). Some studies have also commened that in order to accelerate natural regeneration, management measures, such as the thinning of exotic trees to improve light and nutrient under a plantation canopy, the planting of shade-tolerant native species (like many of the Fagaceae) (Thang 2003; Lee *et al.* 2005; Do and Van 2009), and the planting of native tree species with fleshy fruits for attracting seed dispersers, are needed to rehabilitate the understory community and speed up natural succession (Lee *et al.* 2005). However, the results of these studies have not demonstrated the relationship between the canopy closure and natural regeneration of native species under a forest plantation canopy. Thus far, there have been no studies on the dynamics of seeds, i.e., seed dispersal/germinations in the field, seed predation, or seedling establishment and growth.

There have, however, been many studies on indigenous species for a plantation programme in Vietnam (Chat 1995a; Thiep 1997; Tho 1998; FSIV 2000; Hoan 2002; Khanh 2003), a list of which has been found by researchers (Co 1995; Chat 1995a; Hoan 2002; Khanh 2003; Hien 2004; Tung 2006). It is important to note that most of these studies did not found the light and nutrient demands of species of differing ages, the appropriateness of sites, the relationship with other species, and ecological factors like soil, temperature, and humidity.

The growth and development abilities of indigenous species under plantation canopies have been studied by many different researchers (Chat 1995a; Riikka 1998; Anonymous 1999; FSIV 2000; Senbeta and Teketay 2001; Hoan 2002; Khanh 2003; Piotto *et al.* 2009). They confirmed that the mean annual increment of height and *dbh* of some indigenous species after treatment (opened canopy) are higher than when under a closed canopy. Many studies in Vietnam have found that some promising indigenous species can grow and develop well under a forest plantation canopy (Co 1995; Chat 1995a; Hoan 2002; Khanh 2003; Hien 2004; Tung 2006). However, there have been some limitations to these studies, and there are incomplete gaps in the imformation. Examples of such gaps include site conditions after plantation establishement, the adaptive ability of indigenous species with planting sites, the best time for the transfomation of plantations, the thinning technique of high stratum layer of plantation canopies, thinning intensity, and the maintenance of the optimal canopy closure for periods of time during transfomation. Because these studies would be difficult and complicated, they require more time, funding, equipment, and reseachers. On the other hand, the growth and development of indigenous species will always have a strong relationship with the micro-climate and site conditions that correspond to their location. In order to give the best silvicuture technical guidance for transfomation, some studies linked to indigenous species plantation models should be conducted. The goal of the “5MHRP” is to establish 5 million hectares, 3 million of which were forest plantation. Silvicuture technical guidance for transfomation is very important for both the local Governments and famers. Indeed, studies must meet short and long term goals. For the above-stated reasons, this research is reasonable and neccessary.

1.3 Research objectives

The exotic forest plantation, natural forest, and local species trials in Luc Ngan District, NE Vietnam were assessed. The overall objective of this research is to contribute to the knowledge of the dynamics of site conditions under a plantation canopy and the growth of indigenous species in local species trials. The specific objectives are to:

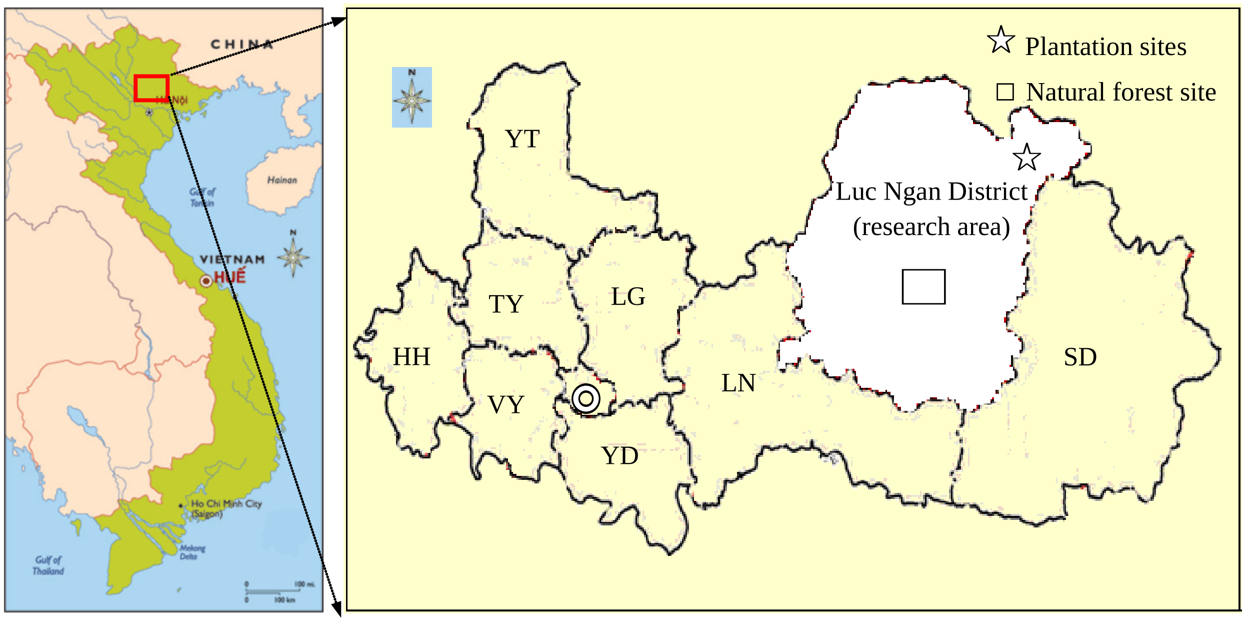
- Analyse natural regeneration characteristics of indigenous species under an exotic forest plantation canopy;
- Assess the growth and development of indigenous species in local species trials;
- Determine the site factor (i.e.nutrient demand) of indigenous species in natural forest;
- Recommend silvicultural management options for the transformation of exotic forest plantation into mixed-forest plantation, considering exotic as well as indigenous species.

2 Materials and Methods

2.1 Research area

2.1.1 Location

The research area is located in Luc Ngan District, Bac Giang Province. This area, with coordinates at 21°18´ to 21°30´ N and 106°30´ to 106°56´ E, belongs to the watershed area of the Luc Nam River. The centre of the district is linked to Bac Giang City by National Highway No. 31, and is located about 60 km from Luc Ngan Town. It is bounded in the north by Lang Son Province, in the west and south by Luc Nam District, and in the east by Son Dong District. The total area of the district is 101,220 hectares, and it contains two specific sub-areas: (1) the lowland, made up of seventeen communes and one town, and (2) the highland, with twelve communes (Anonymous 2006).



YT: Yen The District
SD: Son Dong District
VY: Viet Yen District
TY: Tan Yen District
HH: Hiep Hoa District
◎ Bac Giang City
LG: Lang Giang District
LN: Luc Nam District
YD: Yen Dung District

Fig. 1 The location of the research area in Luc Ngan District, Bac Giang Province, Vietnam (Anonymous 2006)

2.1.2 Topography and climate

The topography of Luc Ngan ranges from average hill sites to steep-sided mountain slopes. It is divided into two areas, the highlands and the lowlands. The highlands occupy nearly 60 % of the district´s total area, with an average altitude ranging from 300 to 400 m (Anonymous 2006). The lowlands covers over 40 % of the total area, with an altitude between 80 and 120 m. Luc Ngan has two main tributaries that flow into the Luc Nam River, Chu and Luc Nam Rivers, which respectively originate in the Loc Binh (Dong Quan Commune) and Son Dong Districts.

The climate of this area is typical for the northeastern part of Vietnam. There are two distinct seasons per year, the dry and the rainy. The rainy season lasts from April to September, with the rain received in June and July making up about 80 % of the total annual rainfall. The dry season runs from October to March. Based on climate data obtained between 2000 and 2012 from the Luc Ngan hydro-meteorological station (Anonymous 2011), the average annual temperature is 24°C, the highest monthly temperature is 29°C, and the lowest temperature is 16°C. The average relative humidity is 81 %, and the average annual rainfall is 1,450 mm. However, because the majority of the rainfall is usually concentrated within two months of the rainy season, sudden floods are known to spontaneously occur in the riparian area. During the dry season, the amount of rainfall is very low, with an evaporation rate 1.8 times greater than the amount of rainfall, particularly in the three months between December and February. This causes the trees in the forest to grow very slowly and develop deep roots. Droughts are often accompanied by the loss of indigenous tree species.

The dry months of the year were calculated based on De Martonne’s aridity index as follows:

$$A_m = \frac{12.n}{Tm + 10} \qquad (1)$$

where A_m = monthly aridity index

n = mean monthly rainfall (mm)

T_m = mean monthly temperature (°C)

Table 1 Summary of hydro-meteorological monitoring (period: 2000 - 2010), data source Luc Ngan Hydro-Meteorological Station (Anonymous 2011)

Month	**Temperature** [°C]	**Rainfall** [mm]	**Humidity** [%]	**Aridity index***
January	16	38	79	18
February	17	27	81	12
March	20	60	83	24
April	25	134	82	46
May	27	167	80	54
June	29	210	82	65
July	29	278	83	86
August	28	225	84	71
September	27	146	83	47
October	25	83	80	28
November	21	50	79	19
December	17	36	78	16
Year	**23**	**1,450**	**81**	

*after De Martonne

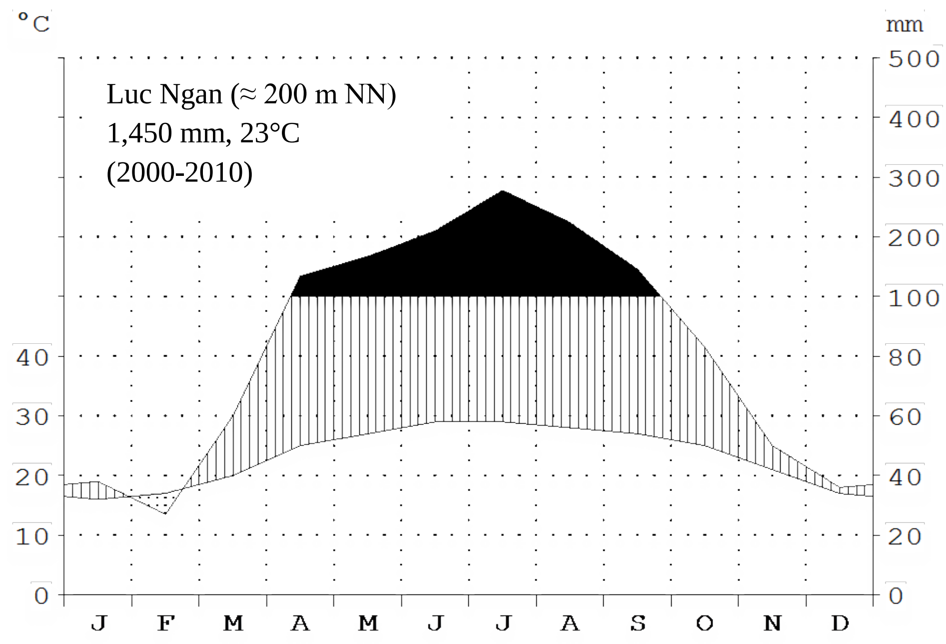


Fig. 2 Climate diagram of the research area. Data source: Luc Ngan Hydro-Meteorological Station from 2000 to 2010 (Anonymous 2011)

The area of research has six months with less than 100 mm of rainfall. As shown in Figure 2, the rainfall curve is always above the temperature curve - however, based on De Martonne's aridity index, there are four dry months with aridity index (A_m) < 20 where the rainfall curve nearly coincided with the temperature curve.

2.1.3 Geology and soil

Most of the area in Luc Ngan District is covered by the light-yellow Ferralsols soil group (FAO system), which is developed on granite and sandstone and is mainly concentrated on high mountains (Anonymous 2006). The soil is divided into six main groups: (1) Ferralsols on low-hills (59.9 %); with an altitude ranging from 25 to 200 m, this group is suited to afforestation programmes, household gardens, and the planting of industrial fruit-bearing trees. (2) Ferralsols on mountains (24.4 %); this group is mainly distributed in steep areas ranging in altitude from 200 to 700 m, and is thus suited for the development of protected or reserve forest. (3) Rice production of flat fields and low-hilly area (5 %); this is accompanied by a thick layer of soil and is suited to the cultivation of irrigated rice, corn, sweet potato, cassava, and vegetables. (4) Alluvial concentrates in valleys and along rivers (2.2 %). (5) Light-yellow Ferralsols on high mountains (1.8 %); this group is developed on granite and sandstone and has, a depth ranging from 30 to 100 cm, making it thus suitable to the development of forest rehabilitation projects. (6) Silt distributed in the lowland (0.1 %).

2.1.4 Vegetation

Luc Ngan District has a total of 35,800 hectares of forested land (35.4 % of the total area), of which 19,700 hectares are used for the protection of watersheds and 16,100 hectares of forest plantation for timber production (Anonymous 2006). The natural forest is categorized into three main forest types:

(1) Natural forest with an average timber volume of 120 to 200 m^3/ha. Mainly distributed in the remote areas (bounded by Loc Binh District, Lang Son Province) and

dominated by the species *Michelia mediocris, Madhuca pasquieri, Vatica tonkinensis, Cinnamomum obtusifolium, Phoebe cuneata, Choerospondias axillaris, Podocarpus nerifolius, Engelhardia chrysolepis,* and *Burretiodendron hsienmu*, it is being selectively logged by local people in the communes.

(2) Natural forest has an average volume of under 120 m^3/ha. This is secondary forest which has been rehabilitated after selective cutting or shifting cultivation. It is concentrated in the low-mountain areas and composed of trees belonging to the families Lauraceae, Fagaceae, Symplocaeace, Theaceae, etc.

(3) Semi-natural forest, concentrated mainly in the two communes of Phong Minh and Sa Ly, has an average timber volume of 30 to 70 m^3/ha. It consists of main species, namely *Schima wallichii* and *Liquidambar formosana*. It is also a type of rehabilitated secondary forest developed after over-harvesting or shifting cultivation.

2.1.5 Socio-economic situation

According to a social survey conducted in 2006 (Anonymous 2006), Luc Ngan had a population of 204,000 people belonging to eight distinct ethnic groups. Of these, the Kinh group is the largest, consisting of 51 % of the population. The population density was 202 people/km^2. Most of the people primarily depend on agriculture, with irrigated rice, cassava, sweet potato, and litchi as the major crops (Anonymous 2007). Forest land was allocated to households for purpose of planting under the Government's land allocation policy, implemented in 1993. However, according to the survey data, most of the plantations cannot yet be harvested, thus delaying the projected income for them. The average per capita income in the district is still low, and the people are forced to resort to the forest at the end of crop season for illegal logging, firewood collecting, and animal hunting. Consequently, this results in increased pressure on the natural forest.

2.1.6 History of plantations in the research area

In 1995, the "KfW1 Project" carried out a "re-greening of the Bare Hills Programme" in the Phu Nhuan, Dong Coc, and Tan Hoa Communes of Luc Ngan District. The objectives of the project were to (i) establish approximately 2,000 hectares of forest plantation and natural regeneration forest with various tree species based on the specific site conditions, and (ii) contribute to the improvement of the ecological environment and the local people's livelihood (MARD 1995a). According to the technical guidelines of the project, natural regeneration was applied to sites where there were over 800 Potential Crop Trees (PCTs) per hectare, evenly distributed over the whole area. Enrichment planting was applied to sites with 400 to 800 PCTs per hectare, and afforestation to those sites with < 150 PCTs per hectare. *Pinus massoniana* and *Acacia auriculiformis* were planted on sites where the soil was barren and thin-layered, with low fertility, low moisture, and a high percentage of stoniness - qualities which are not suited to the growth and development of indigenous tree species. Detailed information on the site conditions before the establishment of the *Pinus massoniana* and *Acacia auriculiformis* plantations are as follows:

According to the field survey results of Luc Ngan District from 1995, the soil was created out of schist/granite, and had a depth of < 50 cm, a pH value (H_2O) from 4.0 to 5.5, low availability of P and N, and low reserves of K, Ca and Mg (Lucngan 1997). It was dominated by three main shrub species (*Rhodomyrtus tomentosa*, *Melastoma candidum,* and *Phyllanthus emblica)* and four main ground vegetations (Fern, *Asarum balansae*, *Dicranopteris linearis,* and *Artemisia annual).* Testing on these plants indicated acidic and degraded soil (Trung 1970), rendering the ground suitable for only *Pinus massoniana* and *Acacia auriculiformis* (MARD 1996b; Duong 2009).

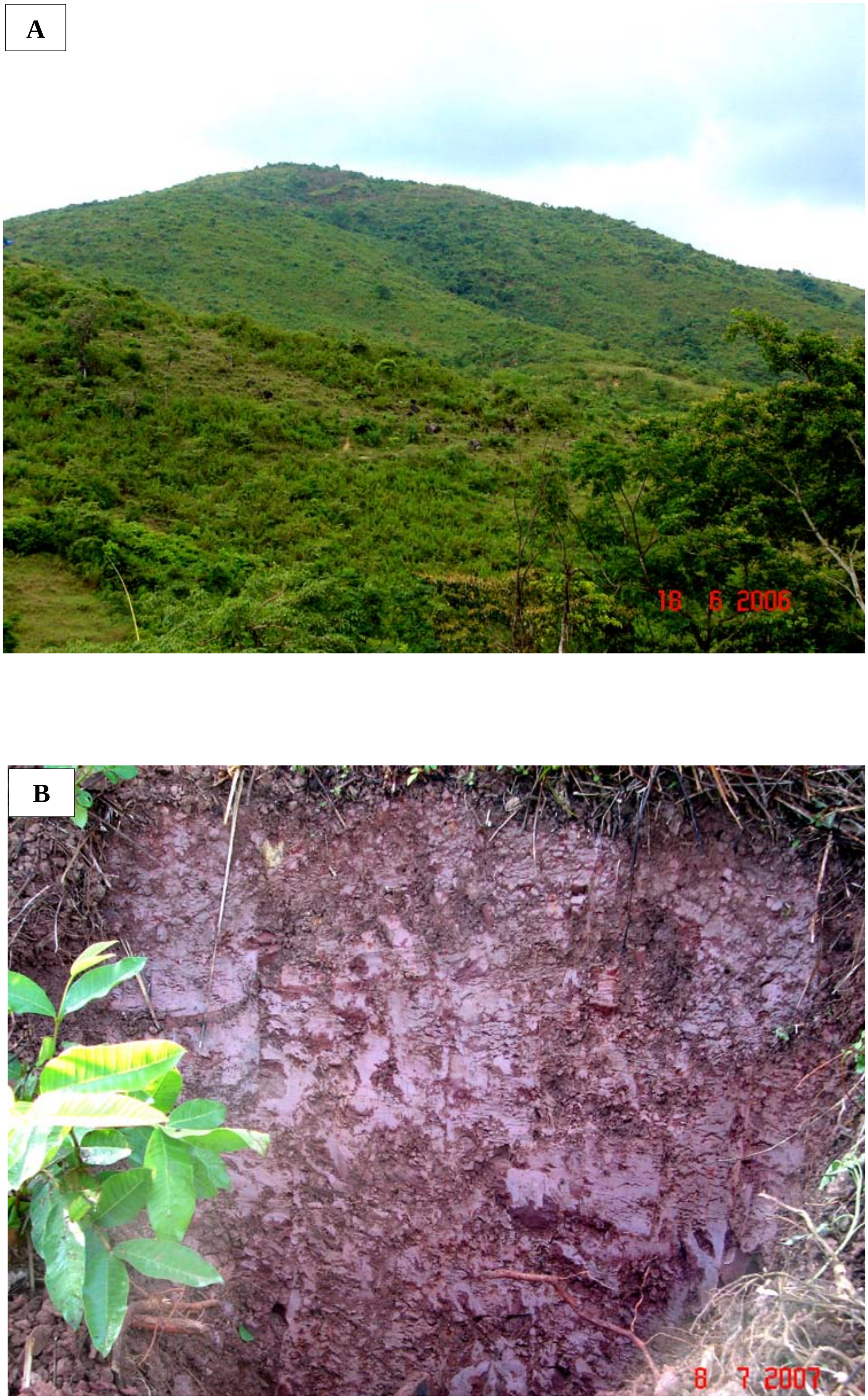


Fig. 3 (**A**) Field site and (**B**) soil profile before the establishment of the forest plantation in Luc Ngan District, Bac Giang Province, Vietnam

During the project´s implementation (1996 to 1998), a total of 2,370 hectares of *Pinus massoniana* and *Acacia auriculiformis* were established in the communes of Phu Nhuan, Dong Coc, and Tan Hoa, Luc Ngan District (Apel 2000). The details of the silvicutural measures applied to the establishment of the *Pinus massoniana* and *Acacia auriculiformis* plantations (MARD 1996b) are as follows:

Seedlings were high vigorous for the first 6 months; the diameter at root collar (*drc*) was ≈ 0.2 -0.3 cm; the total height was ≈ 25 -30 cm; and a disease-free and well-developed root systems with mycorrhiza was present. Planting density was ≈ at 1,660 trees per hectare (spacing of 3 m x 2 m). Seedlings were planted in the strip with a width of 2m. All ground vegetation and shrubbery growing in the planting strips was cleared. The planting pits were alternately dug in a triangular form between the rows, with a dimension of 30 x 30 x 30 cm. A combination of N-P-K (5:10:3) and micro-organism fertilizer was applied at sixty grams per tree. Planting season was from early May to the end of July.

The first year of tending was completed in November. The activities at the time focused on the replacement of failed plants, vegetation clearance in the planting strips, and tilling the soil around the Pit to extend it to 40 - 50 cm in diameter. Tending occurred twice in the second year in March and November. The activities were similar to those from the year before, with the additional use of N:P:K (5:10:3) mixed with micro-organism fertilizer for top-dressing (100 g/tree). The third and the fourth years of tending were respectively done in March and November, the activities during which also focused on the replacement of failures, vegetation clearance in the planting strips, and the refilling of the planting pits with soil around the tree root collar. After the fourth year, the planted trees had developed enough that tending only required focus on the protection against fire, grazing livestock, wild animals, and insects.

Table 2 Sequence of activities for establishing forest plantations in Luc Ngan District, Bac Giang Province, Vietnam

Time schedule [month]	**Activities**
Et – 7	Seedling production in nursery
Et – 2	Site preparation
Et – 1	Pit digging
Et – 0.5	Filling pit and bed – dressing fertilization
Et	Planting
Et + 1	Replacement of failures
Et + 3	First tending. Replacement of failed plants, vegetation clearance in the planting strips, and tilling the soil around the pit
Et + 8	Second tending and top dressing. Similar activities to the first tending, with the additional use of N:P:K (5:10:3) mixed with micro-organism fertilizer for top-dressing (100 g/tree)
Et + 15	Third tending. Activities focus on the replacement of failures, vegetation clearance in the planting strips, and the refilling of the planting pits with soil around the tree root collar
Et + 20	Fourth tending. Activities similar to the third tending
Et + 27	Fifth tending. Activities focus on the protection against fire, grazing livestock, wild animals, and insects
Et + 32	Sixth tending. Activities similar to the fifth tending
Et + 39	Seventh tending. Activities similar the fifth tending
Continuously	Protection (Anti-forest fire, pest, diseases)

Et = time of planting

2.2 Data collection

2.2.1 Research scope

The research area is located in Luc Ngan District, Bac Giang Province and the three types of forest were studied:

a. Plantation forest: three communes in Phu Nhuan, Dong Coc, and Tan Hoa were selected.
b. Natural forest: Xa Ly Commune was selected.
c. Local species trial: two communes in Dong Coc and Tan Hoa were selected.

2.2.2 Forest plantation assessment

The research was carried out at *Pinus massoniana* and *Acacia auriculiformis* plantation sites, established between 1996-1998 in the communes of Phu Nhuan, Dong Coc, and Tan Hoa, Luc Ngan District, Bac Giang Province. A total of forty temporary sample plots (20 m x 25 m) representing each forest type were designed. These were laid out systematically through the area on a gridline of 500 x 500 m with one random starting point (Fig. 4).

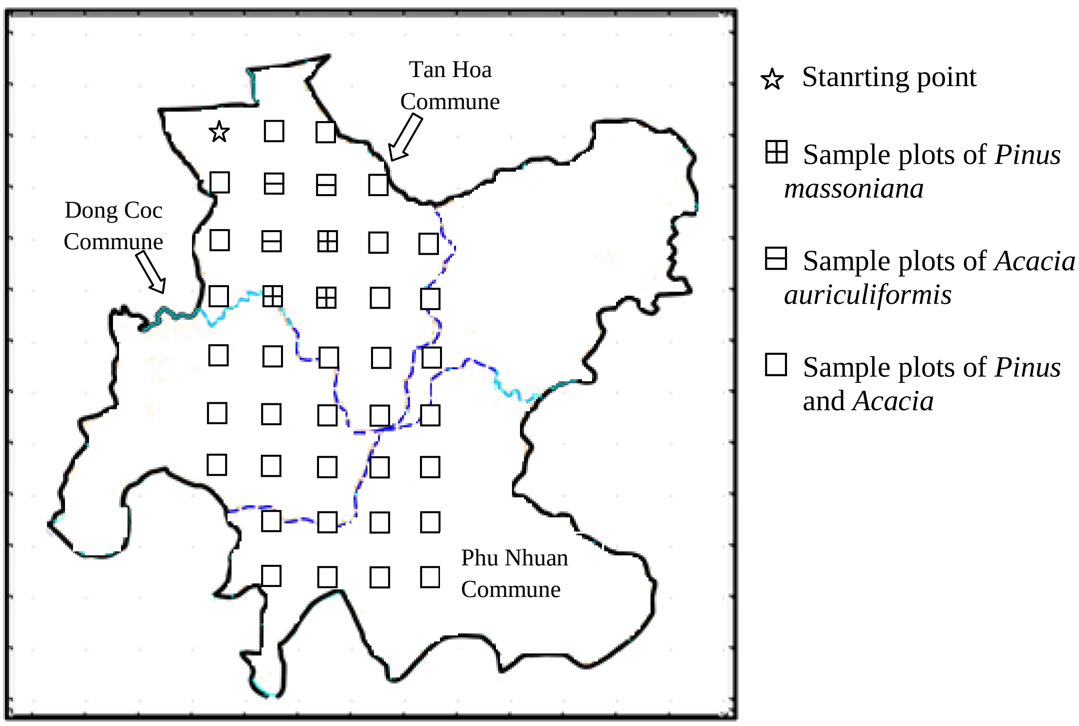


Fig. 4 Layout of the sample plots

In sample plots of 500 m^2 (compartment A), all trees with a diameter of ≥ 5 cm at breast height were measured and recorded. Shrubs, ground vegetation, and natural regeneration of tree species (seedlings and saplings) with the *dbh* < 5 cm were measured and recorded in 25 m^2 subplots (compartment B) located in the corners of each plot. Litter layers were collected in quadrats of 1 m^2 (compartment C) to estimate the fresh weight. This litter was kept in plastic bags and dried in the laboratory of the National Institute of Agricultural Planning and Projection, Vietnam (NIAPP) to estimate the dry weight of litter layers per hectare.

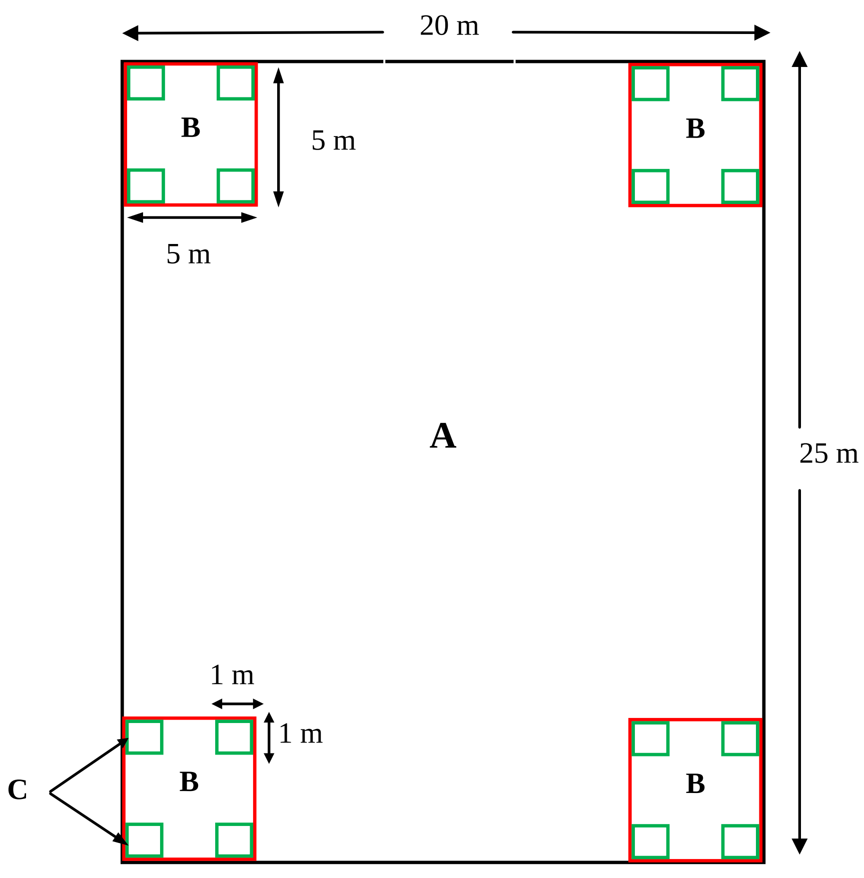


Fig. 5 Stratified design of a single sample plot in a forest plantation in Luc Ngan Distric, Bac Giang Province, Vietnam. **Compartment A**: 40 sample plots x 500 m^2 = 20,000 m^2 for the survey of trees with *dbh* ≥ 5 cm (distance between the sample plots is 500 m); **Compartment B**: 160 subplots x 25 m^2 = 4,000 m^2 for the survey of shrubs, ground vegetation, and natural regeneration of trees with *dbh* < 5 cm; **Compartment C**: 640 quadrats x 1 m^2 = 640 m^2 for the survey of litter layer

2.2.3 Natural forest assessment

A total of nine sample plots of 2,000 m^2 (40 m x 50 m) were set up to represent the three forest types ($IIIA_1$, $IIIA_2$, and $IIIA_3$)[2] in Xa Ly Commune, Luc Ngan District (Figure 6.1). In each plot (Compartment A), all species with a *dbh* ≥ 10 cm were measured and recorded. To investigate trees with the *dbh* < 10 cm, subplots of 25 m^2 (5 m x 5 m) (Compartment B) were set up in the corners of the sample plots to record the regeneration of woody species.

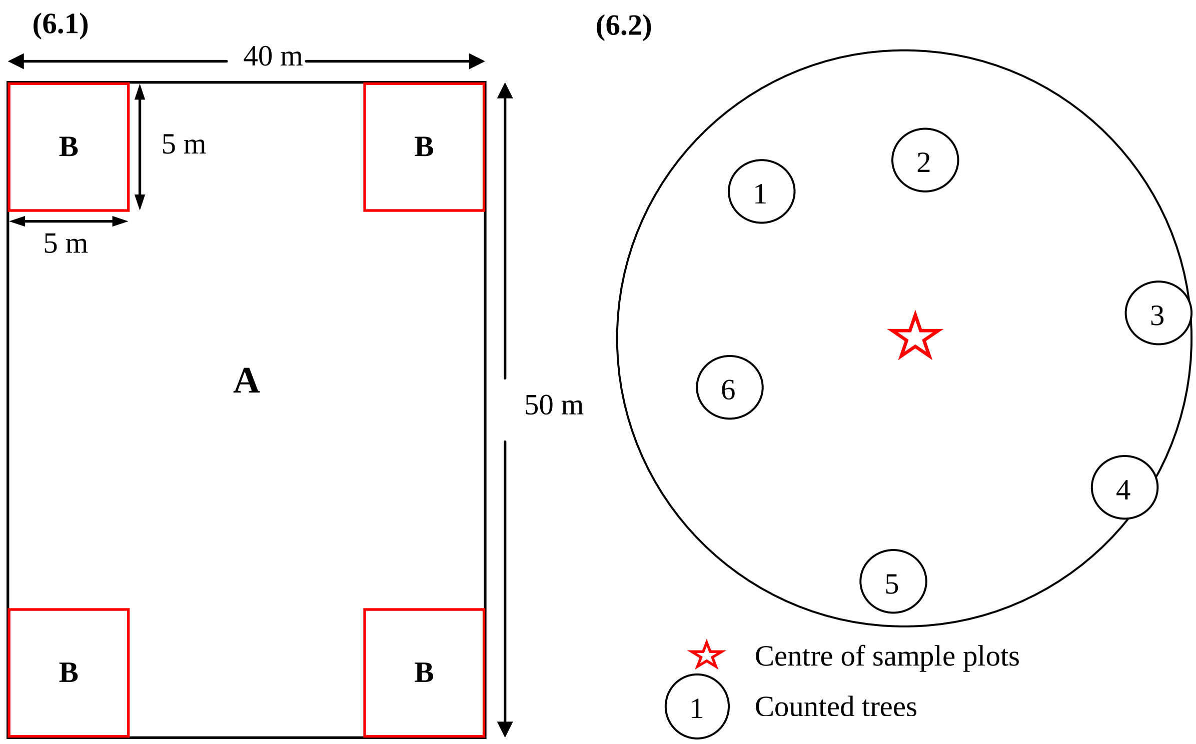


Fig. 6 (6.1) Sample plot design; (6.2) Point-to-tree distance sub-sample plot in natural forest in Xa Ly Commune, Luc Ngan District, Bac Giang Province, Vietnam. **Compartment A**: nine sample plots x 2,000 m^2 = 18,000 m^2 for the survey of trees with *dbh* ≥ 10 cm (three sample plots represented for forest category of $IIIA_1$, three for $IIIA_2$, and three for $IIIA_3$); **Compartment B**: thirty-six subplots x 25 m^2 = 900 m^2 for the survey of shrubs, ground vegetation, and trees with *dbh* < 10 cm. A total of twenty-four point-to-tree distance sub-sample plots represented for categories $IIIA_1$, $IIIA_2$, and $IIIA_3$ for a survey of six trees with *dbh* ≥ 10 cm were nearest the centre of sub-sample plots to identify associated tree species

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[2] Forest classification of Vietnam (MARD 1984)

In order to determine “associated trees,” which usually grow near each other in the natural forest, a total of twenty-four point-to-tree distance sub-sample plots representing the three forest types (fig. 6.2) were established. Six tree species which a *dbh* ≥ 10 cm were nearest the centre of the sample plots (Kleinn *et al.* 2009) and were also investigated.

According to decision No. 682 B/QĐKT dated to the 1st August, 1984 by the Forest Minister of Vietnam on the classification of natural forest (MARD 1984), the category $IIIA_1$ had, as a result of over-exploitation and high-intensity selective logging, an estimated timber volume of 50 - 80 m^3/ha. Timber volume for the category $IIIA_2$ is estimated at 80 - 120 m^3/ha, and for $IIIA_3$ at approximately 120 - 200 m^3/ha.

Tree information of forest plantation and natural forest was identified as follows:

a) Species name - identified in the field by local forest personal. Unknown species were identified at the herbarium of FIPI.
b) Diameter at breast height (*dbh*) - measured at 1.3 m above the ground with diameter tape. The measurement procedure was followed according to (Alder and Synnott 1992; Kleinn *et al.* 2009; Picard *et al.* 2010).
c) Tree height in the natural forest - measured with a Blume-Leiss device. Estimated in the forest plantation by using a 3 m bole.
d) Information on natural regeneration species - consisting of species name, total height, diameter at root collar, vitality, distribution, etc. Seedlings and saplings were classified into height classes of ≤ 30 cm, 31 – 130 cm, 131 – 300 cm and > 300 cm (Lamprecht 1989).
e) The canopy closure - defined by the forest diagram drawing method in horizontal plan (Richards 1996), in combination with the visual estimation method.
f) Information on shrubs and ground vegetation - recorded as species name, height, % of ground cover, and vitality.

2.2.4 Local species trial assessment

Three temporary sample plots of 500 m^2 (20 x 25 m) were randomly selected in each of the seventeen blocks (see appendix 2). A total of fifty-one temporary sample plots were set up in local species trials planted in 2007 in the communes of Dong Coc and Tan Hoa, Luc Ngan District. Survival rate, diameter at root collar (*drc*), total height, and vitality of the trees were measured and recorded. These measurements were repeated over three consecutive years (2008-2010).

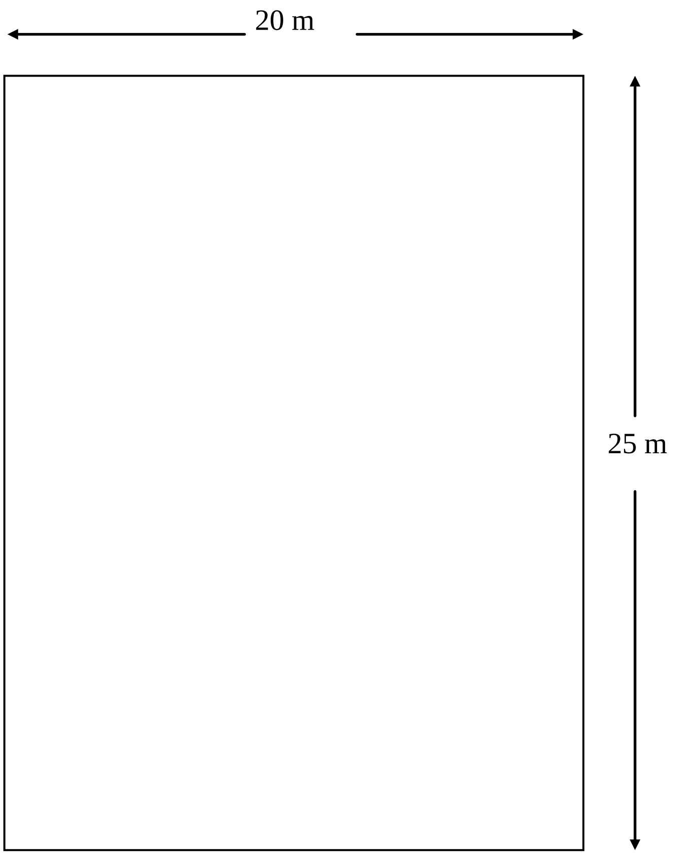

Fig. 7 Layout of the sample plot in local species trials in the communes of Dong Coc and Tan Hoa, Luc Ngan District, Bac Giang Province, Vietnam

2.2.5 Soil analysis

A total of thirteen soil profiles were described at the centre of thirteen sample plots in the forest plantation. The layout of the soil profiles was distributed to represent the different locations (foothill, hillside, and hilltop) and ages of the forest plantation. An additional, one soil profile was also described in the natural forest. General information on the soil was achieved in the field, and included the depth of the soil layer, color, stoniness, and the parent material according to Pancel (1993). Soil samples representing each soil horizon were taken from the profiles, kept in plastic bags and analyzed in the soil laboratory of the National Institute of Agricultural Planning and Projection, Vietnam (NIAPP). The following chemical parameters were determined using standard procedures (Bang *et al.* 1975):

- Soil texture using the pipette method (Gee and Bauder 1986)
- pH using pH meter (Beckman 1934)
- Organic content using the Tiurin method (Tiurin 1951)
- Total nitrogen using the Kjeldahl method (Kjeldahl 1883)
- Micro-oganisms determined by Koch method (Koch 1876)
- Soil porosity caculated as follows:

$$Pt = (1 - \frac{Vs}{Vt}) \qquad (2)$$

where Pt = soil porosity

Vs = the soil particle volume

Vt = total volume

2.2.6 Humidity and temperature measurement

In addition, to record valuable information on the tree species at sample plots in both the forest plantation and natural forest, the humidity and temperature were defined inside and outside the forest by sensor-electronic equipment[3] at each of the sample plot. Measurements were conducted at 9 am, 9:30 a.m, and 10 a.m at three positions (on the

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[3] Identify light intensity by “light meter” and humidity by “max-min thermo hygro” equipment.

ground, 0.5 m, and 2.0 m above the ground). The weather conditions were clear and dry during the measurement assessments.

2.2.7 Data processing

After the completion of the fieldwork, the data was entered into a Microsoft Excel (Office 2007) spreadsheet in standard format for further analysis. The Excel and SPSS 16.0 programs were mainly used for computing forest stand data and diagrams. The ANOVA program was used for the analysis of variance in the differences between the mean diameter/height. The power, inverse, logarithmic, and polynomial functions were selected for curving the fitting of diameter and total height.

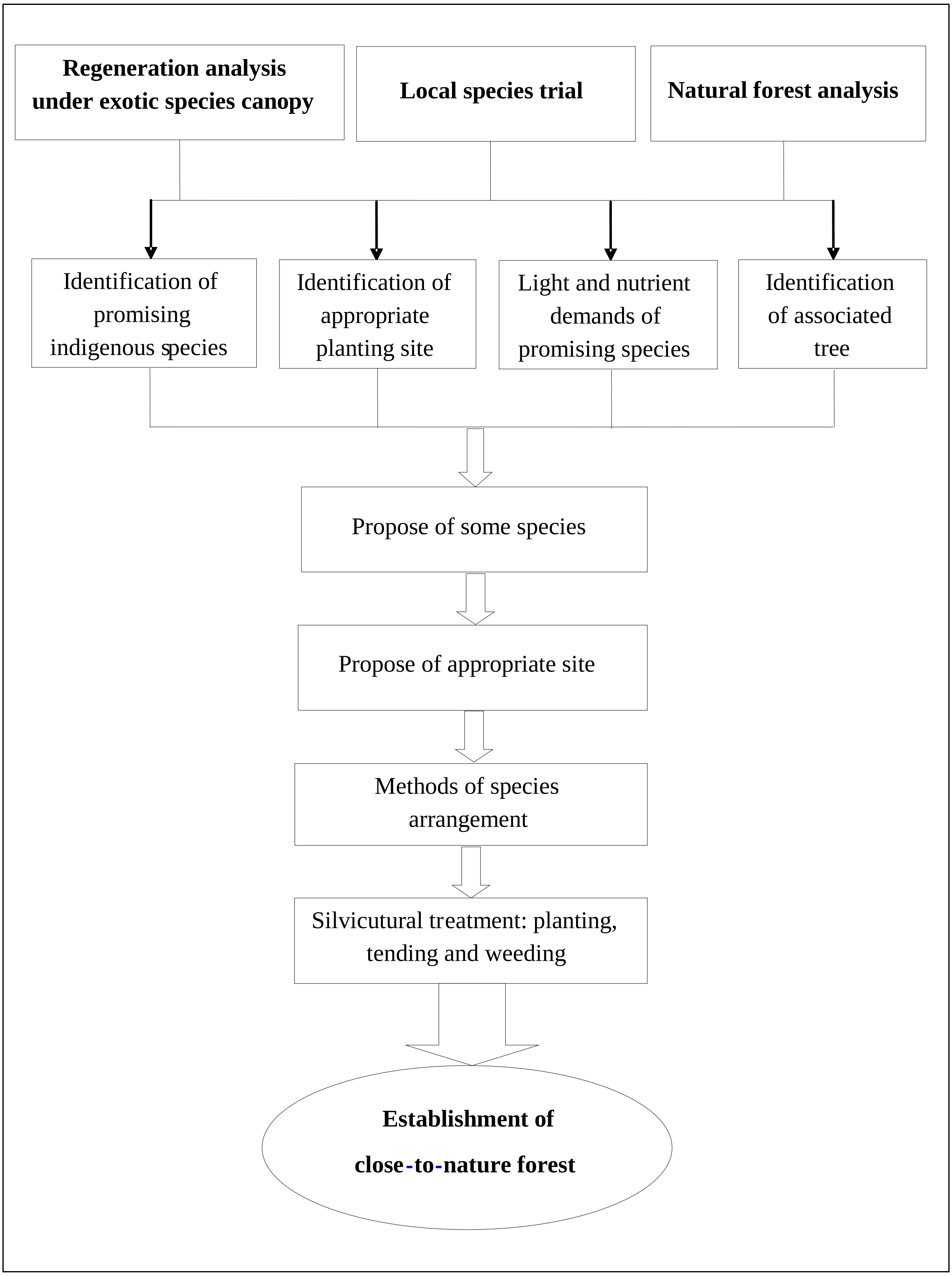


Fig.8 Diagram of research methods

Under the canopy of exotic tree species plantation

Selection of promising indigenous species

Method:

+ Using the subplots of 25 m^2 (5 m x 5 m) to investigate the regeneration of woody species and find the promising ones.

Criterion for selection

+ Height > 1.5 m

+Composition > 5 %

+Growth and distribution of species in an equal pattern.

Selection of appropriate planting site

Method:

+ Using the sample plots of 500 m^2 to investigate tree species with *dbh* ≥ 10 cm.
+ Using quadrate of 1m^2 to collect litter layers.
+ Physical and chemical features of soil were determined by soil profiles.
+ Determined temperature and humidity inside and outside forest.

Criterion for selection

+ Forest plantation grow well in both diameter and height. Density ≈ 1,000 – 1,300 trees/ha; *dbh* ≈ 10 – 15 cm, total height ≈ 7.0 - 10.0 m, canopy closure ≈ 0.5 - 0.7.
+ Density of indigenous regeneration > 1,000 trees/ha and species richness > 18 species.
+ Soil depth > 50 cm, pH value ≈ 5.0 – 6.0, humus layer depth >10 cm and humus content > 5 %.
+ Positions near by streams or foothill, slope < 20 degree.

Local species trial

Selection of best species

Method:

+ Using the sample plots of 500 m^2 (20 m x 25 m) to record and measure the survival rate, increment, and quality of indigenous tree species.

Criterion for selection

+ Survival rate of species > 85 % in the third year.

+ *MAI* > 0.9 cm in diameter and > 0.8 m in height; > 80 % of good trees quality.

Assessment and proposal of appropriate site

Criterion for selection

+ Survival rate of trial plot > 85 % in the third year.

+ *MAI* > 0.9 cm in diameter and > 0.8 m in height; > 80 % of good tree quality.

+ Positions by streams and below the hillside, slope < 20 degree.

+ Soil > 50 cm, pH value ≈ 5.0 – 6.0.

Natural forest

Light and nutrient demands of selected species

Method:

+ Using sample plots of 2000 m^2 to inventory tree species with *dbh* ≥ 10 cm.

+ Physical and chemical features of soil were determined by soil profiles in order to note the nutrient demand of the species.

+ Measurement of temperature and humidity inside and outside the forests in order to determine the light, temperature, and demands of species in the natural forest.

Selection of associated trees

Method:

The point-to-tree distance method was applied to find the associated trees, which usually grow near each other in the natural forest.

Fig. 9 Detail of the research

3 Results and discussion

3.1 Forest plantation assessment

3.1.1 Status of plantations

Forest plantation stands were established between 1996 and 1998 in Phu Nhuan, Dong Coc, and Tan Hoa Communes of Luc Ngan District, Bac Giang Province, Vietnam. A total area of 2,370 hectares of *Pinus massoniana* and *Acacia auriculiformis* plantations have been established on degraded lands. An average density of 1,120 trees per hectare, the growth of a mean diameter and height after ten years was of 10 cm and 8 m, respectively. Beside, site conditions and the micro-climate under the plantation canopies have been positively significant change and as a result the process of natual regeneration is favourable. Some species with high commercial value in fruits, bark, and timber have been found under the plantation canopies. However, there is still a potential risk, in that pure plantations of *Pinus massoniana* and *Acacia auriculiformis* are frequently infested. In 2002 and 2003, a hight percentage of pure *Pinus massoniana* stands in Luc Ngan District was effected by pests (Dung *et al.* 2008). It is therefore neccessary to conduct a research in order to transfer pure plantations into mixed-plantations.

Characteristics of forest plantation stands

Structural characteristics of forest stands, such as tree density, basal area, tree frequency, stand height, species composition, and volume are a part of any silvicultural stand investigation (Hung 2008). However, in the various tree attributes, diameter and total tree height are probably of the greatest importance (Kleinn *et al.* 2009) and they are the most widely used descriptors of stand structure (Husch *et al.* 2003). Diameter is in most cases easily and directly measured to calculate the basal area. Furthermore, it is closely correlated to timber volume (Kleinn *et al.* 2009). In the forest inventory, the total volume and biomass of trees can be estimated based on diameter and total tree height. There are several ways to calculate the mean tree diameter of stand. The most common expression being arithmetic (Van Laar and Akca 1997). The arithmetic mean diameter, total height and crown width of forest stand were calculated as:

$$\bar{d} = \frac{\sum_{i=1}^{n} d_i}{n} \qquad (3)$$

where $\bar{d}$ = mean diameter (height or crown width) of stand

d_i = diameter (height or crown width) of the individual tree

n = total number of trees of stand

Standard deviation of diameter, height, and crown width of forest stand was calculated as (Kleinn *et al.* 2009):

$$S = \sqrt{\frac{\sum_{i=1}^{n}(Xi - \bar{X})^2}{n-1}} \qquad (4)$$

where S = standard deviation

$\bar{X}$ = estimated mean

Xi = observed valued of i

n = number of tree in the sample

The data from the sample plots was collected and analysed by SPSS software to determine the mean value of diameter and height of the forest plantations at three locations (foothill, hillside, and hilltop). The results in Table 3 show that the average density of these stands was 1,120 trees per hectare, with a mean diameter (*dbh*) of 9.7 cm, a mean total height of 7.6 m, and a mean crown width of 4.1 m. The detailed information is given in Table 3:

Table 3 Mean and standard deviation (SD) of density, *dbh*, height, and crown width (*CW*) of mixed *Pinus massoniana* and *Acacia auriculiformis* plantation stands at various locations and plantation ages in Luc Ngan District, Bac Giang Province, Vietnam

	Density [n/ha]	**Sample plot*** [n]	**dbh** [cm]	**Height** [m]	**CW** [m]
Locations**					
Foothill	1,112	5	**9.1** ± 3.5	**6.9** ± 3.7	**4.0** ± 1.4
Hillside	1,120	10	**9.9** ± 3.5	**7.2** ± 3.7	**4.1** ± 1.4
Hilltop	1,130	5	**8.6** ± 3.4	**6.6** ± 3.4	**3.6** ± 1.3
Plantation ages***					
11-year-old	765	5	**11.2** ± 3.8	**9.8** ± 4.1	**4.5** ± 1.2
10-year-old	1,080	10	**10.1** ± 3.5	**7.8** ± 3.3	**4.1** ± 1.4
9-year-old	1,281	10	**9.7** ± 3.4	**7.6** ± 3.0	**4.2** ± 1.2
Mean			**9.7** ± 3.5	**7.6** ± 3.5	**4.1** ± 1.3

*sample plots of 500 m^2 (20 m x 25 m); ** ten-year-old plantation; *** Foothill and hillside locations

There is a significant difference in diameter and height growth not only between the various plantation ages (P<0.05) but also between the diffirent locations, namely foothill, hillside, and hilltop. The main reason for this lies in the average soil depth at the various locations of the sites. In the foothill and hillside locations, the soil had a depth of > 30 cm, while on the hilltops, it had < 30 cm. This means that the growth rate of diameter and height in hillsides is likely to be higher than at other places. Consequently, the site conditions (including the micro-climate and soil) at a hillside locations are the most suitable for growth and development of trees.

A – Pure *Acacia auriculiformis* plantation

B – Mixed *Pinus massoniana* and *Acacia auriculiformis* plantation

Fig. 10 (**A**) Ten-year-old pure *Acacia auriculiformis* plantation; (**B**) Ten-year-old mixed *Pinus massoniana* and *Acacia auriculiformis* plantation at Dong Coc Commune, Luc Ngan District, Bac Giang Province.

Diameter distribution

Diameter distribution, or the so-called distribution of the number of stems in relation to diameter, is an important and descriptive stand characteristic. It reflects their ecological characteristics of flora and the protective function of the forest (Hung 2008). Furthermore, it also reflects the history of forest interventions (Felfili 1997). Various studies have analysed the diameter distribution in tropical forests (Richards 1952; David *et al.* 2008). The shape of the diameter distribution is affected by many factors such as: the sampling area, the width of diameter classes, and tree distribution (Rubin *et al.* 2006).

Fig. 11 (**A**) shows that, the histogram´s trend of a *Pinus massoniana* stand inclines towards the left side, indicating that the forest plantation was still in a young phase and has not yet undergone strong competition for living space among the individuals in the stand. The density of the *Pinus massoniana* stand was twice higher than that of the *Acacia auriformis* stand. The number of individuals in the plantation stand mainly focused on the diameter classes of 6 – 12 cm with one main canopy layer. The density increased markedly from 129 trees in the 6 cm class to 228 trees in the 8 cm class. In the following *dbh* classes, the data declined significantly, with very few trees in *dbh* classes of ≥ 18 cm. By observation results in the field, the stand grew slowly with low branched, big and many branches, short trunk, crook, thin crown, and was regularly infested by pest. Besides, a self-thinning process had already occurred but was not yet wide-spread.

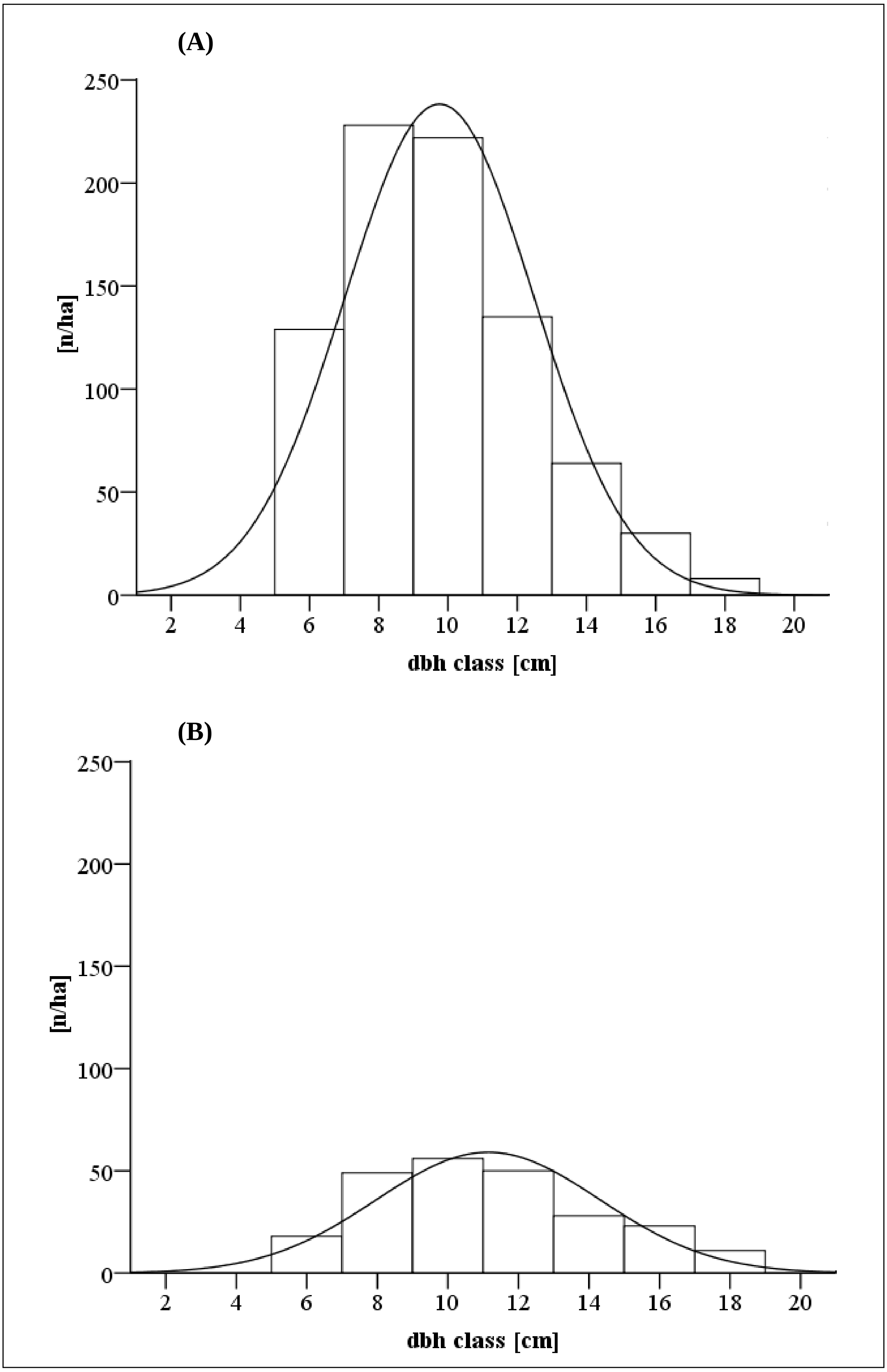


Fig. 11 Diameter distribution of ten-year-old forest plantation stands in Luc Ngan District, Bac Giang Province, Vietnam; fitted *poisson* distribution:
(**A**) *Pinus massoniana* stand: mean *dbh* = 9.4 cm; Std.Dev = 2.8 cm; *n* = 841
(**B**) *Acacia auriculiformis* stand: mean *dbh* = 11.2 cm; Std.Dev = 3.6 cm; *n* = 248

The mean *dbh* of the *Acacia auriformis* stand was higher than that of *Pinus massonina*. According to Chinh *et al.* (1996) *Acacia* is a fast growing species, with high adaptability for severe site conditions. The growth rate of *dbh* is usually higher than for *Pinus* species. Fig. 11 (**B**) illustrates that the trend of the histogram is in proportion and most trees were in the 8 – 12 cm *dbh* classes. The number of trees increased slightly from eighteen trees in the 6 cm class to fifty-six trees in the 10 cm class, after which the figure reduced to twenty three trees at 16 cm, not exceeding 20 cm. The plantation stand had two main canopy layers. The higher one was dominated by trees with the height > 10 m, straight bole, and large crown. In contrast, the lower one was occupied by trees with the height < 10 m, with low branches, short trunk, crook and thin crown. The competition and self thinning were occuring in the stands. Some small trees in the lower canopy had died due to the lack of light, water, and nutrients.

Based on the diameter distribution, pruning and thinning techniques can be applied in order to adjust the forest structure and stand density. These measures create the best condition for the growth and development of stands, and promote the natural regeneration of indigenous species under plantation canopies.

Height curve

The direct observation of some tree variables, such as tree volume and height is time-consuming and costly. Thus, it may help to establish a statistical relationship between the target and easier-to-obsever variables, for example *dbh*. The relationship is formulated as mathematical functions, which are then used as prediction models to anticipate the value of the target dependent variable once the value of the easy-to-measure independent variable is known (Kleinn *et al.* 2009). In natural forests, measuring the diameter of trees is much easier than their height, because the sheer luxuriance in these forests prevents from seeing the whole length of the trunks (Hung 2008). Therefore, if the relationship between the trees´ diameter and height is found, the height value will be easily predicted from the *dbh* value.

In this research, the height curves were drawn with a data set of 115 *Pinus massoniana* and 46 *Acacia auriculiformis* trees. Seven common functions were tested in order to find the best fit to the observed data and the highest correlation coefficient value (r^2). Based on the correlative level among the parameters, the standard errors, and the existence of parameters, the *polynomial function* was the best fitting function expressing the correlation between the height and diameter of the *Pinus massoniana* and *Acacia auriculiformis* stands. Equation is as follows:

$$h = a_1 (dbh)^2 + a_2 (dbh) + a_3 \quad (5)$$

According to Van Laar and Akca (1997) and Loetsch (1973), the shape of height curves is related to site conditions. The slope of a curve is determined by the relative growth of the *dbh* and height. It can also provide an indicator for the development and growth stages of the stand. When the slope is steep, the stand is still young and conversely (Brack 1999). The research findings show that, the *Acacia auriculiformis* stand was more mature than the *Pinus massoniana* one although its height curve seemed to be steeper than that of the counterpart (Fig. 12). Most of *Pinus massoniana* stems were less than 10 m in height. The flat slope of the curve means that the plantation stand was young without high competition among the trees for light and nutrients. At the same time, the vertical competition among trees in the *Acacia auriculiformis* stand is happening simultaneously. The curve of *Acacia auriculiformis* stand is steeper than that of the *Pinus massoniana* stand. In such cases, it is understood that there was a strong competition between individual trees leading to the death of some small trees under the canopy. Besides, the stand density had been decreased by selective logging of local people and the selft thinning of the small trees layer.

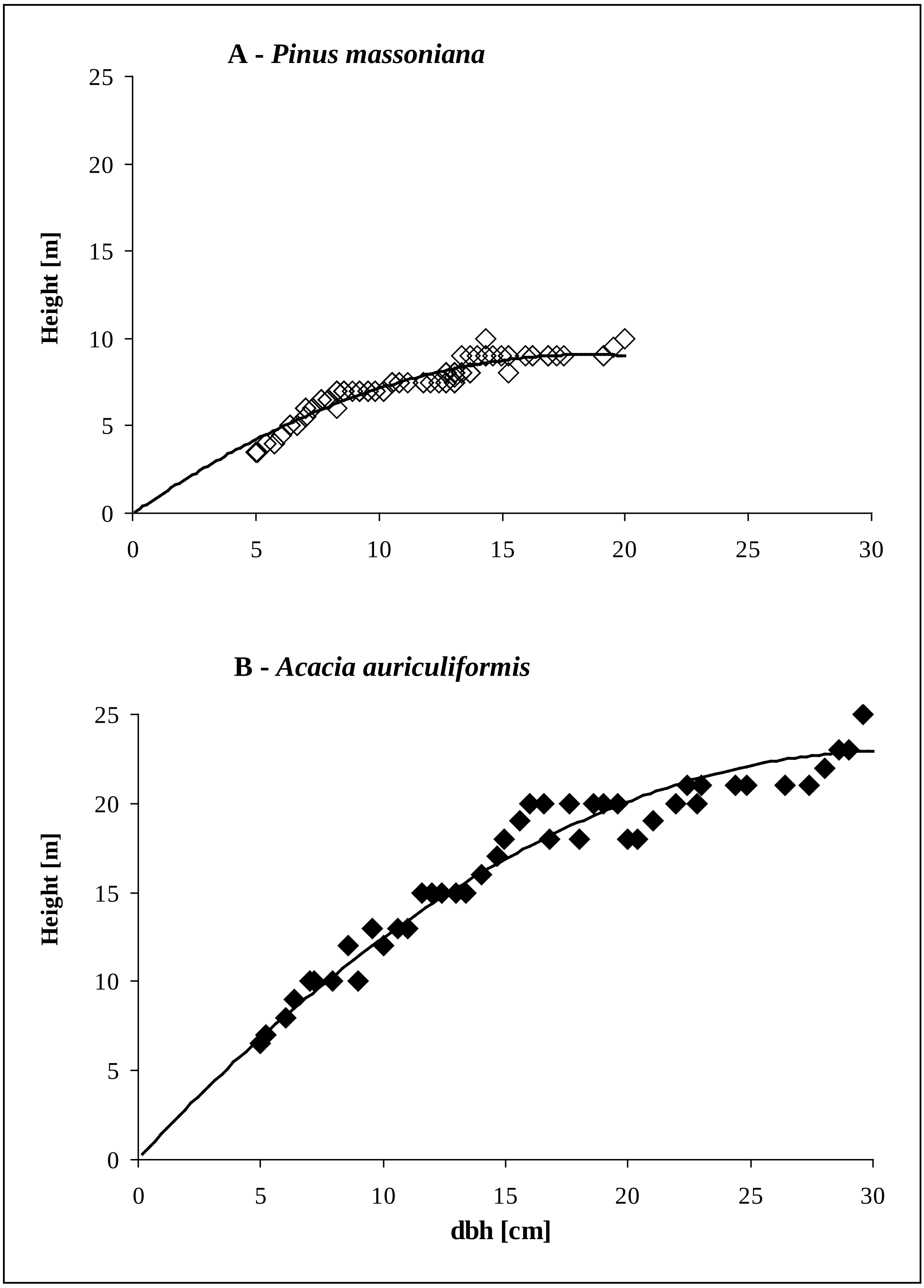


Fig. 12 Height curves of ten-year-old forest plantation stands (*dbh* ≥ 5 cm) in Luc Ngan District, Bac Giang Province, Vietnam; fitted polynomial equation:
(**A**) *Pinus massoniana* stand: $h = -0.026(dbh)^2 + 0.983(dbh) - 0.051$; $r^2 = 0.92$; n = 115 trees; $P < 0.001$
(**B**) *Acacia auriculiformis* stand: $h = -0.021(dbh)^2 + 1.4(dbh) + 0.715$; $r^2 = 0.95$; n = 46 trees; $P < 0.001$

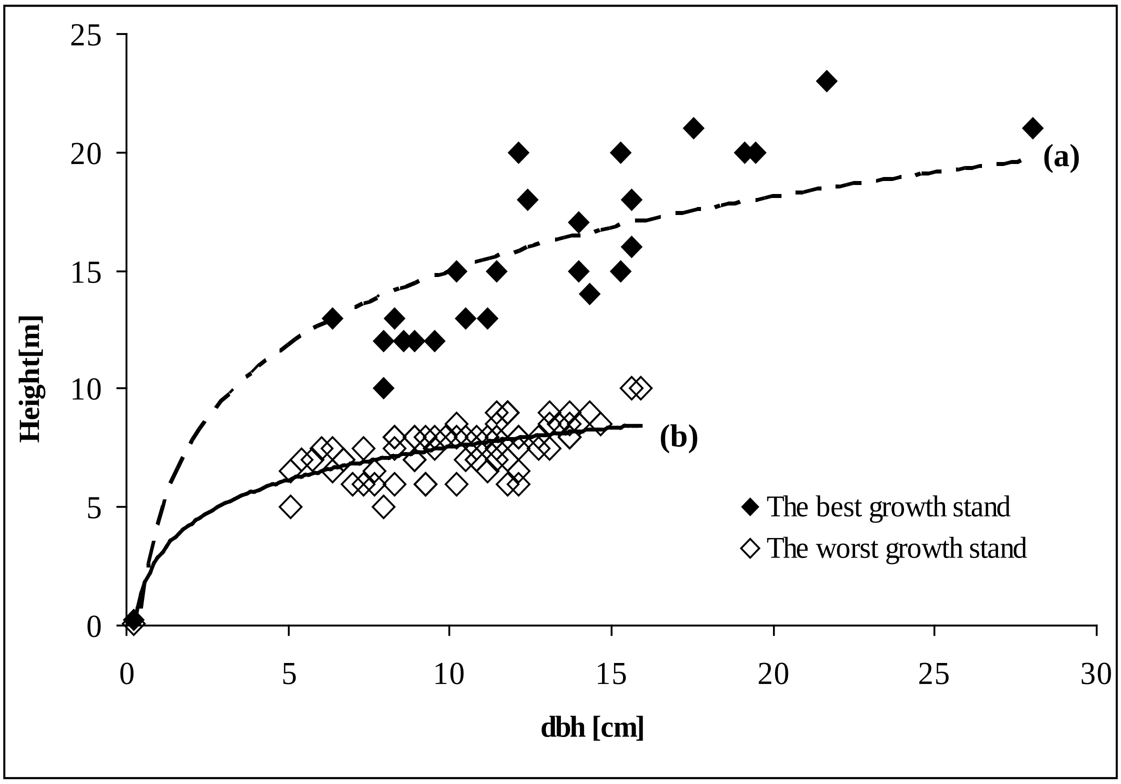


Fig. 13 Height curves of (**a**) the best growth of ten-year-old *Acacia auriculifomis* plantation and (**b**) the worst growth of ten-year-old *Pinus massoniana* plantation growth stands ($dbh \geq 5$ cm) in Luc Ngan District, Bac Giang Province, Vietnam; fitted with logarithmic equation:
(a) $h = 4.544 \ln(dbh) + 4.528$; $r^2 = 0.73$; n = 25 trees; $P < 0.001$
(b) $h = 2.006 \ln(dbh) + 2.919$; $r^2 = 0.61$; n = 71 trees; $P < 0.001$

The shape of the height curves shows clear difference between the best and the worst growing stands (Fig. 13). The height curve of a fast growing stand is steeper than that of a slow one and the *r* value is also higher (0.73/0.61).

Based on the results of this research, the following silvicultural measures showed be applied including: thinning, tending, and enrichment planting to create favourable conditions for the growth and development of trees in order to improve yield, quality, and maintain the protective function of the plantation. Furthermore, they promote the natural regeneration of indigenous species.

3.1.2 Soil variation and dynamics

Site conditions are often regulated by soil´s physical and chemical properties, which in turn affects water and nutrient availability (Sucre *et al.* 2011). Previous studies demonstrated that the soil and micro-climatic conditions under the vegetation cover can be improved much faster than those under pastures and bare land areas. Lee *at al.* (2006) proved that *Acacia* plantations contained higher soil enzyme activities than grasslands. In addition, forest plantation is efficient in accelerating the invasion of tree species, improving various site qualities (micro-climate and soil conditions). Moreover, soil nutrients and soil organic matter in the degraded areas can be improved by forest plantation (Jordan and Farnworth 1982; Lugo 1992; Lugo *et al.* 1993; Parrotta 1995; Michelsen 1996).

Physical properties

The physical, chemical, and ecological soil properties are derived from the properties of the individual phases (minerals, soil organic matter, water, air). Their spatial distribution, defined as soil structure, characteristics the individual soils and was used for classification (Pancel 1993). The soil profile reflects physical properties. However, these properties are constantly changing during the soil formation.

A number of thirteen soil profiles was described and laid out in accordance with the various locations. In order to futher define the level of change in the soil properties, three soil profiles were set up under plantation canopies with an average elevation and slope of 112 m a.s.l. and 20° respectively. The space time method was used to determine the soil variation and dynamics (Walker *et al.* 2010). The first soil profile was located in a bare hill with site conditions similar to those where forests had previously been planted (1997). The second profile was situated at a five-year-old mixed *Pinus massoniana* and *Acacia auriculifomis* plantation. The third was constructed at a ten-year-old mixed *Pinus massoniana* and *Acacia auriculifomis* plantation.

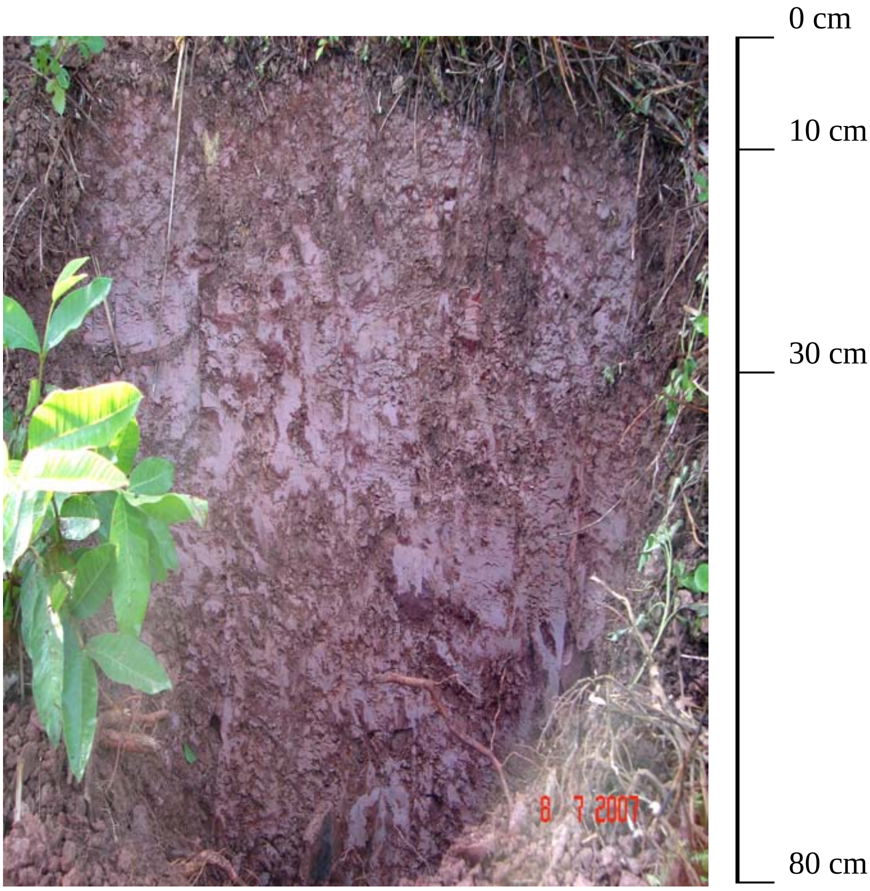


Fig. 14 Soil profile at bare hill representing the situation before the establishment of a forest plantation (1997) at Thuong B Village, Dong Coc Commune, Luc Ngan District, Bac Giang Province, Vietnam

Before 1997, famers had applied unsuitable cultivation techniques for such an extended amount of time that the soil became degraded and eroded away. It is clearly seen in the soil profile (Fig. 14) that there was no “O” horizon, a high ratio of concretions, and a dry land surface. Indeed, after ten years of forest plantation which protected the land surface, the soil became gradually fertile (Fig.15). The “O” horizon re-appeared due to the decomposed organic matter (OM) of the branches and leaves. The concretion ratio significantly decreased, and the soil moisture distinctly increased in comparison to moisture levels before. The research finding is similar to the results achieved by Grubb (1995) where plantations promoted a regeneration of the understory by shading out grasses, increasing the nutrient status of top soils through litter fall, and facilitating the influx of site-sensitive tree species.

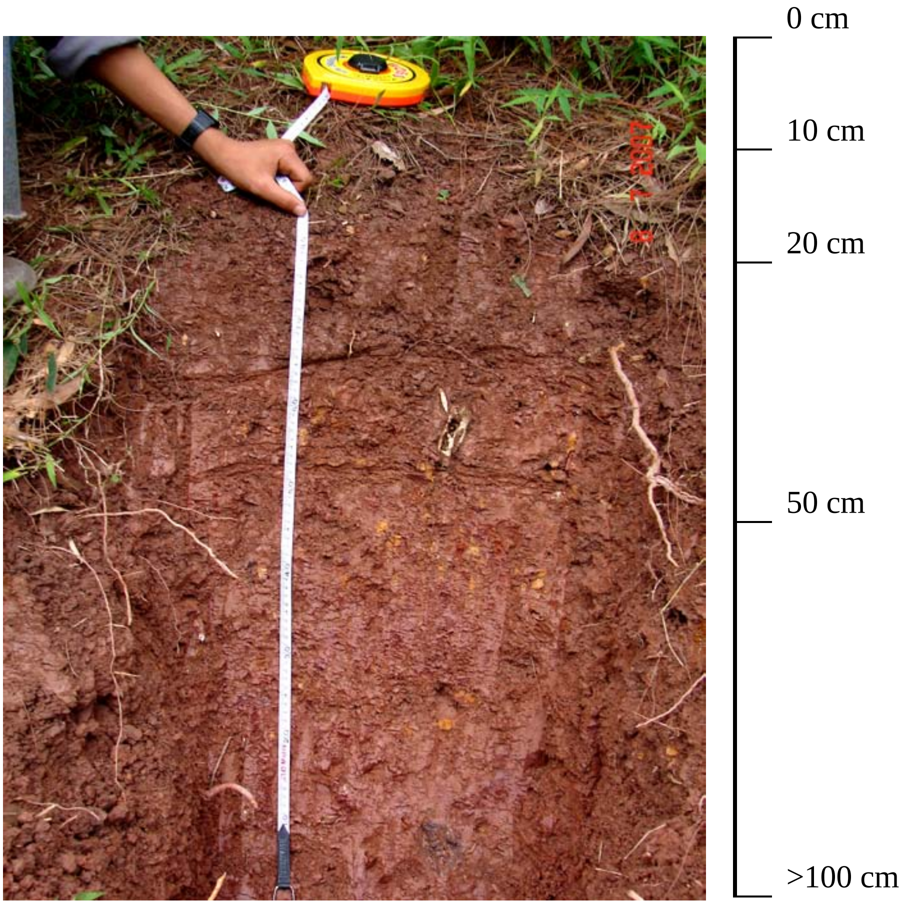


Fig. 15 Soil profile under a ten-year-old mixed *Pinus massoniana* and *Acacia auriculiformis* plantation canopies at Thuong B Village, Dong Coc Commune, Luc Ngan District, Bac Giang Province, Vietnam

The comparative analysis of soil profiles also indicates an erosive phenomenon of clay and a deep leaching of clay in bare hills due to the lack of a vegetation cover for a long period of time. The percentage of clay increased slightly from 23 % to 26 % during the time period of ten years under forest plantation. This confirms that the vegetation plays a vital role in preventing erosion, leaching and surface water run-off.

Table 4 Physical soil properties during the time period of sequences (1997; 2002; and 2007) in Luc Ngan District, Bac Giang Province, Vietnam (analysed in the soil laboratory of the National Institute of Agricultural Planning and Projection, Vietnam [NIAPP])

Time period of sequences	Depth soil layer [cm]	Soil bulk density [g/cm^3]	Soil porosity [%]	Soil texture		
				Sand [%]	Silt [%]	Clay [%]
Bare hill (1997)	0-30	1.35	49	45	32	23
Five-year-old plantation (2002)	0-30	1.34	50	45	31	24
Ten-year-old plantation (2007)	0-30	1.20	53	43	29	26

A depth of 0-30 cm the soil density on a bare hill was 1.35 g/cm^3 in 1997. It declined by 1.34 g/cm^3 after five years (2002) and to 1.2 g/cm^3 after ten years (2007). On the same period of time, soil porosity rose up from 49 % to 53 % (Table 4). The main cause of this change is again that the land surface was covered by vegetation after planting which does not only prevent erosion, and surface water run-off, but also improve fertility, increase the humus content and the number of soil organisms.

Chemical properties

A crucial feature of forest land is the accumulation of organic matter and nitrogen by the mineralization cycle. Organic materials on forest land are provided by branches and leaves. However, the accumulative process of organic matter is always closely dependent on climate, elevation, parent materials, especially the soil particles and vegetations.

The cultivation of local people (slash-and-burn) can be considered as the main cause of both the loss of supply sources of organic matter and the decrease of the number of micro-organisms. Moreover, the erosion and leaching processes of nutrients are quickly leading to degraded land. After ten years planting, the organic matter was 1.5 times as high as in the bare hill, and both $N_{totally}$ and $P_2O_{5\ totally}$ went up considerably, whereas the acidity in the topsoil declined significantly (Table 5). The results state that the average dry-weight of the litter layer was roughly 4.6 tons per hectare. Furthermore, the observations in the field also indicate that over a period of ten years (1997 – 2007), the accumulaton of litter layer increased more than 12 cm.

Table 5 Chemical soil properties during the time period of sequences of soil at the layer depth of 30 cm (analysed in the soil laboratory of the National Institute of Agricultural Planning and Projection, Vietnam [NIAPP])

Time period of sequences	**pH** [H_2O]	**pH** [KCL]	**OM** [%]	**Totally of NPK** [%]			**Availability of NPK** [mg/100g]		
				N	P_2O_5	K_2O	N	P_2O_5	K_2O
1997*	5.1	4.0	1.5	0.13	0.01	1.94	4.2	1.9	10.8
2002**	5.2	3.8	1.8	0.10	0.02	1.55	4.2	2.0	9.5
2007***	5.9	4.2	2.1	0.14	0.03	1.29	5.6	2.1	8.4

(*Bare hill; **Five-year-old plantation; ***Ten-year-old plantation)

This demonstrates that the vegetation plays a critical role in changing the availability of N, P_2O_5, K_2O, and minerals. This is supported by the results of Chandrapal *et al.* (2010) achieved from a 4-8 years old *Eucalyptus* plantation in Bahabhar and Tarai region of Indian central Himalaya. Which indicate that the pH decreased after planting, and contributed to alkalify the soil than the *Eucalyptus* plantation.

To summarize, the negative application of cultivation techniques and over-exploitation over a long period of time have caused to soil erosion, leaching, and degradation. The vegetation cover plays a significant role to prevent these negative consequences.

Soil micro-organisms

Microbes are important to maintain soil fertility and productivity, in the cycling of nutrient elements. They play a key role in the decomposition of organic matter, the remnants of plants or animals, to inorganic matter (Mette *et al.* 2002; Avis *et al.* 2008).

However, soil micro-organisms heavily depend on forest cover and the composition of vegetations (Hoorman and Islam 2010; Hoorman 2011).

The results in Appendix 1 state that the number of micro-organisms per 100 g soil rose quickly from 1.67 $x10^7$ to 6.58 $x10^7$ after ten years planting.

In conclusion, micro-organisms, a key component, produce enzymes for the humus formation and compound decomposition in the nitrogen cycles. They also play a vital role in the ecosystems. Their types and quantities depend on both site conditions and the types of vegetation. The role of vegetations creates a favourable environment for the regeneration and activities of micro-organisms. On the other hand, micro-organisms contribute to the decomposition of organic matters, to increase humus contents, and to create favourable conditions for the growth and development of vegetations (Balloi *et al.* 2010; Hoorman 2011).

Variation of soil characteristics at different altitudes

The soil properties differ at the various locations within the forest plantations (Fig. 16). The pH value at the hillsides was markely different from those locations in the foothill or on the hilltop, where the lowest soil acidity was found. The foothills usually had higher acidity, due to the lack of vegetation cover. Additionally, soil erosion and leaching nutrients occured rapidly at positions where the elevation was high. Cation Al^{3+} and H^+ were solubilized in rainwater and deep leaching.

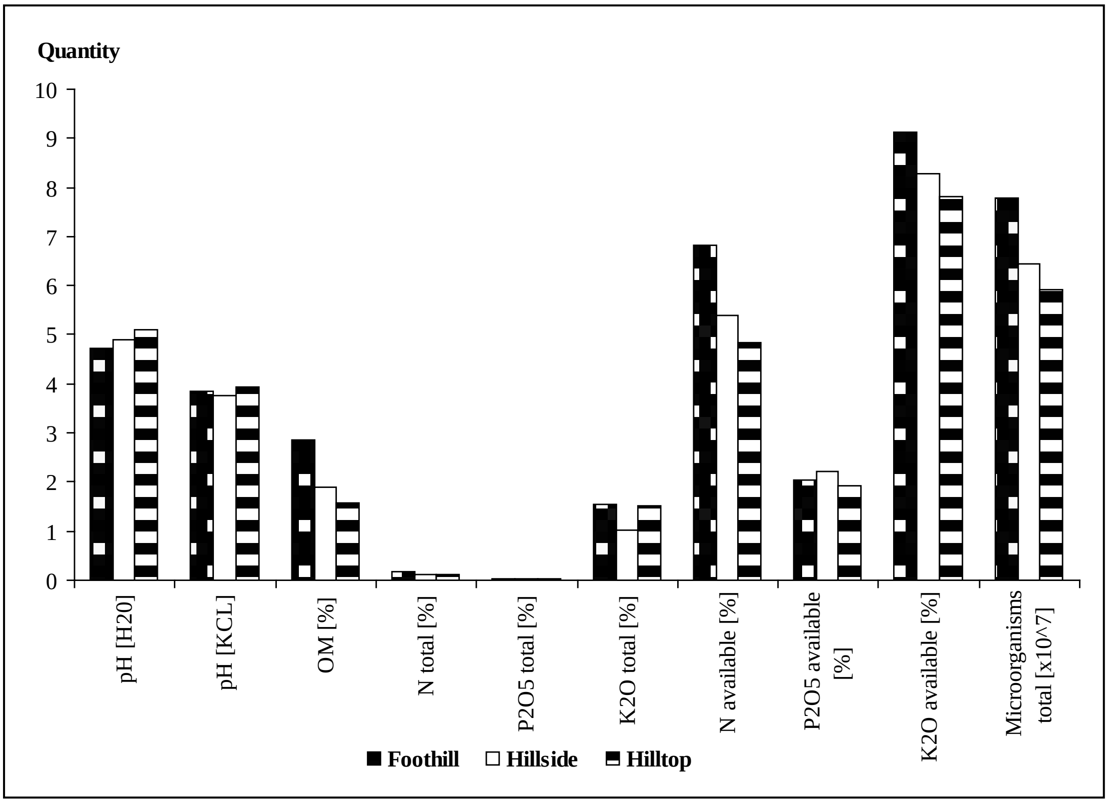


Fig. 16 Comparison of soil properties at various positions in a ten-year-old mixed *Pinus massoniana* and *Acacia auriculiformis* plantation (analysed in the soil laboratory of the National Institute of Agricultural Planning and Projection, Vietnam [NIAPP])

The results also show that the soil layer at foothills was usually deeper than that of hillside and hilltop. The growth and development of plantations at foothill and hillside locations were better than at hilltops and the amount of micro-organisms was also higher. As a result, the decompositive process of organic matter was very fast, and the soil was more fertile (Appendix 1).

In conclusion, ten years after planting, both the physical and chemical properties of the soil changed considerably in a positive way. The erosion and leaching of soil nutrients declined markedly at areas covered by plantations. The pH value decreased while N, P_2O_5 and humus content increased. Site conditions at the foothills under the ten-year-old forest plantation are considerd as suitable for planting indigenous tree species.

3.1.3 Ecological features under plantation canopies

Types of vegetation, forest structure, and canopy closure influence micro-climate (Wenger 1984; Raich and Tufekciogul 2000). Moreover, the micro-climate is a result of the interactions among various biological, biophysical, hydrological, and topographical factors in an ecosystem. It has been considered as the "pulse" of the ecosystem because of its direct and indirect effects on most of the ecosystem (Xu *et al.* 2004). Vegetation cover can change soil temperature and moisture (Gates and Murray 1980). Therefore, it plays a critical role in forming the micro-climate through changes in energy, input and loss the reduction of air and surface soil temperature, and increase in relative humidity (Cruz *et al.* 1994; Xu *et al.* 2002).

Previous researches further indicate that ecological factors such as light, stand structure, root system of mother trees, shrubs, and ground vegetation influence regenerated trees. The most important of these factors is light, which directly influences the regeneration under the forest canopy (Lamprecht 1989; Hung 2008; Benjamín 2009).

Temperature

The data of forty temporary sample plots show that the average temperature inside the plantations was 32°C. While, outside the forest it was 35°C. A comparison of the temperature at three positions (ground, 0.5 m, and 2.0 m) inside and outside the forest proved little different as inside (32.9°C on the ground, 31.6°C at a height of 0.5 m, and 32°C at 2.0 m) but significant differences outside (37.4°C on the ground, 34.3°C at 0.5 m, and 33.5°C at 2.0 m) (Fig. 17).

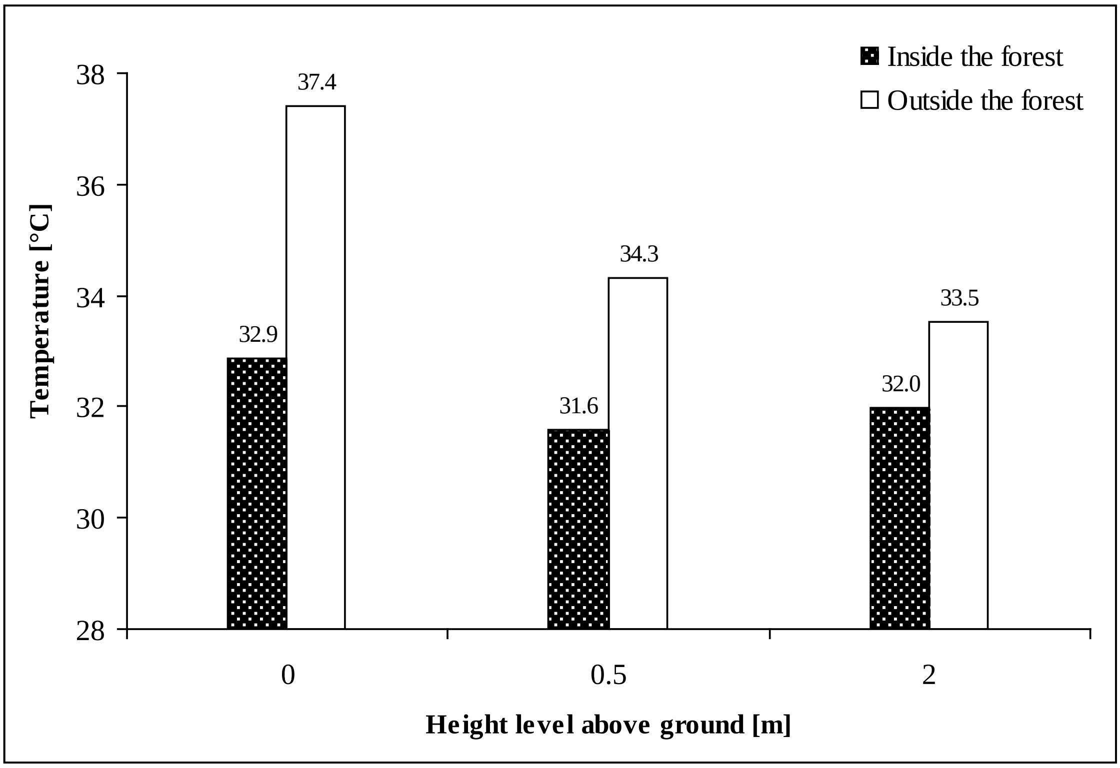


Fig. 17 Temperature at three different positions inside and outsite of a forest plantation in Luc Ngan District, Bac Giang Province, Vietnam, recorded in July, 2007

The measured positions in the forest were covered by canopy, the forest floor only received light scattered, resulting in a temperature that barely changed between positions. At some locations without vegetation, the temperature quickly increased and was higher than inside forest. The temperature at the land surface was usually higher than at other positions. It directly influences the growth and development of plants, especially roots and cotyledons. Heat-resistance ability of indigenous species is limited and the cells of roots and cotyledons will be destroyed by high temperature.

Humidity

In general, the humidity in the forest is higher than in areas without the forest due to the lower temperature and the transpiration from the leaves (Wenger 1984). Besides, the forest canopy can reduce the evaporation in forest (Ulrich 2008). The results of this research show that the average humidity inside the forest was 68 %, compared to 57 %

at positions which were outside of the forest. The light intensity and temperature affected the humidity between inside and outside of forests.

To conclude, the changes in temperature and humidity are favourable for the growth and development of broad-leaved indigenous tree species after planting.

3.1.4 Native tree regeneration under exotic plantation canopies

Natural regeneration is a biological characteristic and process of the ecological forest system in which over-mature trees within the forest are replaced by young ones (Lan 1991). It is a process of reproducing and expanding the forest (Huyen 1997). In the forestry, natural regeneration is assessed based on species abundance, diversity, quality, and the distribution of seedlings and saplings.

The canopy closure of the forest stand directly influences the density and vitality of seedlings (Yanes and Smith 1982; Oliver and Larson 1996). In the natural forest, some seeds cannot germinate beneath closed canopies because the litter physically prevents them from reaching suitable germination sites. If the overstory canopy open up more seedlings will survive and grow into the sapling bank. Regeneration is easily visible on the forest floor (Oliver and Larson 1996). In Karpov´s study (1969) on the relationship between seedlings and the stand, the complicated competition for soil nutrients, light, and humidity was demonstrated. The relationships among flora depend on the biological characteristics, ages, and ecological conditions of the plant communities. If two species with the same demand for nutrients, light, and water, are growing next to each other, they will compete for resources and may restrain each other´s growth (Them 1992). Based on their light needs, Lamprecht (1989) classified trees into three distinct groups - light-demanding, opportunist, and shade-tolerant.

According to the MARD (1995a), the research area was still covered by natural forest in 1960-1970. Due to extended over-havesting during the next decade, the natural forest decreased in both quality and quantity. After 1980, most of forest areas in the study site were used for agricultural purposes by the locals applying a slash-and-burn system.

Because the forest land was exhaustedly exploited for many years, the soil regains its fertility slowly.

The natural forest is located 5 km away from the research area making seed dispersal to the researched plantation is difficult. However, some indigenous species, such as *Canarium album*, *Castanopsis boisii*, *Erythrophleum fordii*, and *Machilus ordoratissima*, have been planted in household gardens located only 300 to 500 m away from the research plantation; birds and animals, mainly Squirrels and Foxes, feed upon *Canarium album* and *Castanopsis boisii* seeds, which supplements the seed sources of the plantation.

Although there are some seeds with a strong germination capacity (*Erythrophleum fordii)* to be found the plantation (MARD 1996b), natural conditions for their germination are not entirely favourable. Rapid germination of seeds and high survival rate of seedlings are only found in places where the site conditions (humidity, temperature, and light intensity) are suitable for germination (Pancel 1993; Richards 1996). Seeds have difficult germinating on sites with severe conditions – and even if they successfully germinate, their chances for survival are very low.

The goal of this research is to assess the natural regeneration characteristics of indigenous species at different locations under the plantation canopy. In order to appropriate plantation areas for the transformation into mixed plantations, the specific biological characteristics of the indigenous tree species in the research area show that most of them are light-demanding (FIPI 1996), but require shading in their young phase due to their limited resistance to severe conditions (FIPI 1996; Hung 2008). If the site conditions for indigenous tree species are met, they will demonstrate high grow rates. If any species had a higher frequency of regeneration as seedlings under the plantation canopy, their adaptation capacity was as markedly higher than that of other species. Additional studies also indicate that survival rate and growth depend on both the light levels close to the ground surface and the different species′ shade tolerance (Robert and Colombo 2001). This research has consequently focused on the capacity and level of broad-leaved indigenous tree species natural regeneration under plantation canopies.

The findings are expected to indentify the best suited species and areas for mixed plantations.

Species composition and density

Tree species composition (so-called relative abundance) is both a criterion indicating the proportion of tree species or a group of tree species in the stand (Trung 1970; Richards 1996) and a standard for the evaluation of biodiversity and stability in the forest ecosystem (Thuong 2003). In the forest inventory, it is used to illustrate the upper and regeneration layers. The species composition reflects the relationship among the tree species in a plant community in the natural forest (Trung 1970).

Seedlings and saplings of twenty species belonging to fourteen families were found in the research area. Of these, ten species are classified as being greatly preferred by the local people due to their high economic value. They have been planted in some forest stands and household gardens within the research area.

Two of these ten species (*Canarium tramdenum* and *Canarium album*) have commercial value in their fruits; three others (*Litsea acutivena, Litsea glutinosa,* and *Cinnamomum obtusifolium*) have commercial value in their bark; the five remaining species *(Liquidambar formosana, Melia azedarach, Schima wallichii, Erythrophleum fordii,* and *Michelia mediocris)* are valued as timber, and the latter three species in particular are much-preferred for house and furniture material. These tree species have recently been recommended for local and national afforestation programmes in Luc Ngan District (Binh *et al.* 2004a).

Altogether, twenty species belonging to nine families were found in 160 subplots (25 m^2) with an average density of 1,098 trees per hectare. These families all had a relative abundance higher than 5 %. At 28 %, Apocynaceae had the highest relative abundance, followed by families Lauraceae (20 %), Burseraceae (15 %), and Fabaceae (9 %). Meliaceae, Capparidaceae, and Magnoliaceae reached at approximately 5 %.

Table 6 Density, dominance and frequency of natural regeneration species under forest plantation canopies in Luc Ngan District, Bac Giang Province, Vietnam. Based on 160 subplots of 25 m^2 (= 4,000 m^2)

Dominance is the basal area of root collar per ha
Frequency is the percentage of subplots in which a given species occurred

Species	**Family**	**Density** [n/ha]	**Dominance** [m^2/ha]*	**Frequency** [%]**
Wrightia annamensis	Apocynaceae	305	0.16	58
Litsea glutinosa	Lauraceae	233	0.08	60
Canarium album	Burseraceae	100	0.05	40
Melia azedarach	Meliaceae	70	0.06	28
Erythrophleum fordii	Caesalpiniaceae	73	0.03	45
Cinnamomum obtusifolium	Lauraceae	65	0.03	33
Michelia mediocris	Magnoliaceae	60	0.03	38
Liquidambar formosana	Hamamelidaceae	35	0.06	23
Crateva nurvala	Capparidaceae	65	0.01	30
11 other species		93	0.05	100
Total		**1098**	**0.56**	

Note: ***Dominance** = $G_i/\sum G_j$; ** **Frequency** = $f_i/\sum f_j$ x 100
where $\mathbf{G_i}$ is the basal area of root collar, and $\mathbf{f_i}$ the absolute frequency of species, $\mathbf{G_j}$ and $\mathbf{f_j}$ are the total values of the stand.

As seen in Table 6, *Wrightia annamensis* and *Litsea glutinosa* dominated the forest, accounting for 50 % of the stand density and their frequency in the subplots was slightly 60 %. Eleven other species had a density of 93 trees/hectare.

Table 7 Number of indigenous regeneration trees classified by height classes under forest plantation canopies in Luc Ngan District, Bac Giang Province, Vietnam. Based on 160 subplots of 25 m^2 (= 4,000 m^2)

Species	**H ≤30** [cm]	**31-130** [cm]	**131-300** [cm]	**> 300** [cm]	**Percentage*** [%]
Wrightia annamensis	18	172	124	11	28
Litsea glutinosa	58	81	102	3	21
Canarium album	3	72	32	0	9
Erythrophleum fordii	0	32	45	0	7
Melia azedarach	11	18	34	11	6
Cinnamomum obtusifolium	0	45	24	0	6
Crateva nurvala	8	49	11	0	6
Michelia mediocris	0	51	13	0	5
Liquidambar formosana	0	5	28	2	3
11 other species	7	44	37	8	8
Total	**105**	**568**	**449**	**35**	**100**

(* Relative abundance)

A number of the naturally regenerated trees were concentrated at 31 – 130 cm and 131 – 300 cm (Table 7); and 42 % of the stems was higher than the mean height of the shrub layer (130 cm). Because they did not face competition from shrubs and ground vegetation, they will become promising species and the Potential Crop Trees (PCTs). On the other hand, the regeneration trees with less than 130 cm height (lower than the shrub layer) accounted for 58 %. If their environmental adaptability is weak, the trees will die in the severe site conditions.

The survey results indicate that the regeneration process had only recently occurred (within the last 2-3 years). Most of them (84 %) were young trees with small diameter ≤ 3.5 cm at the root collar. Only a small percentage of trees had a diameter > 3.5 cm. However, the high-quality regeneration trees made up a large proportion (55 %), while the moderate-quality trees consisted of just 38 % of the stand.

Species diversity

Species diversity (or so-called α-diversity) is defined as the number of different species in a particular area (Hung 2008) and is dependant on the diversity of small trees in the lower layers. Thus, the conservation of small trees in the lower layers, particularly in the bottom layer, is essential for the sound maintenance of the forest (Feroz *et al.* 2006; Hagihara *et al.* 2008). There are two approaches to measure species diversity, both of which incorporate information on the number of species (species richness) and the relative abundance of individuals within each species (species abundance) (Hamilton 2005). Numerous indices for diversity measurement are the most widely used. The Evenness index expresses how evenly the individuals are distributed among various species (Khan 2004), whereas the Shannon index emphasizes on the rare species (Weidelt 1999), as shown below.

Shannon index (*H'*) (Magurran 1988)

$$H' = -\sum_{i=1}^{s} pi \ln pi \quad (6)$$

where p_i = proportion of individuals that belong to the species i

Evenness index (Brower and Zar 1984)

$$J' = \frac{H'}{H \max} \quad (7)$$

where H' = Shannon index

$H_{\max}$ = ln$S$

S = total species appeared

Considering different plantation ages (9, 10, and 11 years). The species richness and density of indigenous tree species that regenerated under the canopy of a ten-year-old plantation were highest (Table 8). Most areas of the ten-year-old plantations had been set up where the site conditions, including the soil depth and nutrients, were appropriate. The condition for the natural regeneration of indigenous species, seemed tobe most appropriate and the growth rate of vegetation was faster than at other positions.

The greatest values of species richness, density, and diversity indices were found at hillside locations, whereas species diversity at the hilltop positions was limited due to severe site conditions that negatively influenced growth and development (Table 8). The research on the growth and development of the upper story (Chapter 3.1.1) revealed similar results – namely, that the growth rate, increment in diameter, and height of mixed *Pinus massoniana* and *Acacia auriculiformis* plantations was best at hillside locations.

Table 8 Species diversity in different plantation ages, locations and plantation types in forest plantation stands in Luc Ngan District, Bac Giang Province

	Subplot [n]*	**Species richness** [mean ± SD]	**Density** [mean ±SD]	**Shannon index**	**Evenness index**
Plantation ages**					
Eleven-year-old	20	**13** ± 1.6	**840** ± 60	2.4	0.94
Ten-year-old	60	**20** ± 2.1	**1,360** ± 68	2.4	0.79
Nine-year-old	40	**15** ± 1.7	**986** ± 62	2.0	0.73
Locations**					
Foothill	40	**15** ± 1.7	**1,050** ± 48	2.1	0.79
Hillside	60	**19** ± 1.8	**1,360** ± 69	2.4	0.81
Hilltop	20	**6** ± 1.0	**620** ± 90	1.1	0.62
Plantation types***					
Pinus massoniana	12	**8** ± 1.3	**1,070** ± 89	2.0	0.97
Acacia auriculifomis	12	**10** ± 1.5	**900** ± 64	2.2	0.96
Acacia & *Pinus*	60	**18** ± 2.1	**1,190** ± 69	2.3	0.80

*subplot of 25 m^2 (5 m x 5 m); ** Mixed *Acacia auriculifomis* and *Pinus massoniana* plantation; *** Foothill and hillside locations

Natural regeneration furthermore depends on plantation types (Lee *et al.* 2006). The mixed *Acacia* & *Pinus* plantations had the highest level of diversity and density, as well as the strongest capacity to naturally regenerate, as evindenced by the data: a species richness of 18, an average density of 1,190 trees per hectare, and Shannon and Evenness indices of 2.3 and 0.80 respectively (Table 8). These results are similar to those carried out by Carnevale *et.al* (2002) who study regeneration of indigenous under mixed and pure plantations. They found a greater abundance of individuals and species diversity in the mixed plantation than in their pure counterparts. Guariguata (1995) and Montagnini (1999) also confirmed that mixed plantations can, by creating greater variability of habitat conditions, and favoring seed dispersal, germination, and growth of the tree species, promote the regeneration of a greater diversity of species in their understories than pure-species plantations.

Sörensen´s similarity index

The Sörensen index is a very simple measure of β diversity, ranging from a value of 0 where there is no species overlap between two communities, to a value of 1 when exactly the same species are found in both communities (Wolda 1981).

$$Ks = \frac{2c}{a+b} x100 \qquad (8)$$

where a = the number of species recorded in sample A
b = the number of species recorded in sample B
c = the number of species in common between A and B

Table 9a Similarity coefficient of Sörensen (Ks) (%) of the various mixed *Acacia auriculifomis* and *Pinus massoniana* plantation ages in Luc Ngan District, Bac Giang Province, Vietnam

Plantation ages	**Nine-year-old** [Ks]	**Ten-year-old** [Ks]
Nine-year-old	---	80
Ten-year-old	80	---
Eleven-year-old	58	79

Table 9b Similarity coefficient of Sörensen (Ks) (%) of the various locations under ten-year-old mixed *Acacia auriculifomis* and *Pinus massoniana* plantation in Luc Ngan District, Bac Giang Province, Vietnam

Locations	**Foothill** [Ks]	**Hillside** [Ks]
Foothill	---	82
Hillside	82	---
Hilltop	38	48

Table 9c Similarity coefficient of Sörensen (Ks) (%) of the various ten-year-old plantation types at foothill and hillside locations in Luc Ngan District, Bac Giang Province, Vietnam

Plantation types	***Pinus*** [Ks]	***Acacia*** [Ks]
Pinus	---	67
Acacia	67	---
Pinus and *Acacia*	54	71

The Sörensen´s index in Tables 9a, b, and c shows that different ages, locations, and plantation types did always host common species, ranging from 38-80%. However, there was little similarity in species between nine and eleven-year-old mixed *Acacia auriculifomis* and *Pinus massoniana* plantations. The Sorensen´s similarity index was heighest when comparing foothill and hillside locations (82 %), and lowest between foothill and hilltop locations (38 %). Observation found out that there was a significant difference in the site conditions (altitute, soil depth) between the two locations, resulting in the differences in the species composition of natural regeneration.

Height distribution of regenerated species

The number of individuals at different plantation ages, locations, and types of plantation decreased with increasing height class, with the exception of all trees ≤ 30 cm,

As seen in Fig. 18 (a), the density of natural regeneration under a ten-year-old plantation canopy was higher than under both an eleven-year-old and a nine-year-old one. In the height classes of 31-130 and 131-300 cm, 600 and 574 seedlings per hectare were counted respectively. However, in the same height classes only 460/260 seedlings were recorded in the eleven-year-old plantation and 557/307 in the nine-year-old plantation.

Fig. 18 (b) also indicates that the regeneration figures greatly depend on the locations. Hillside locations always contained more regeneration than the other two locations, with 630 seedlings in the height classes of 31-130 cm and 540 in 131-300 cm. In these repective height classes, however, only 508/392 trees were found in the foothill and 460/120 on the hilltop. These results are linked with those reported in Chapter 3.1.2, indicating that the fertility and humidity of the soil in hillside locations is always better in comparison to other locations.

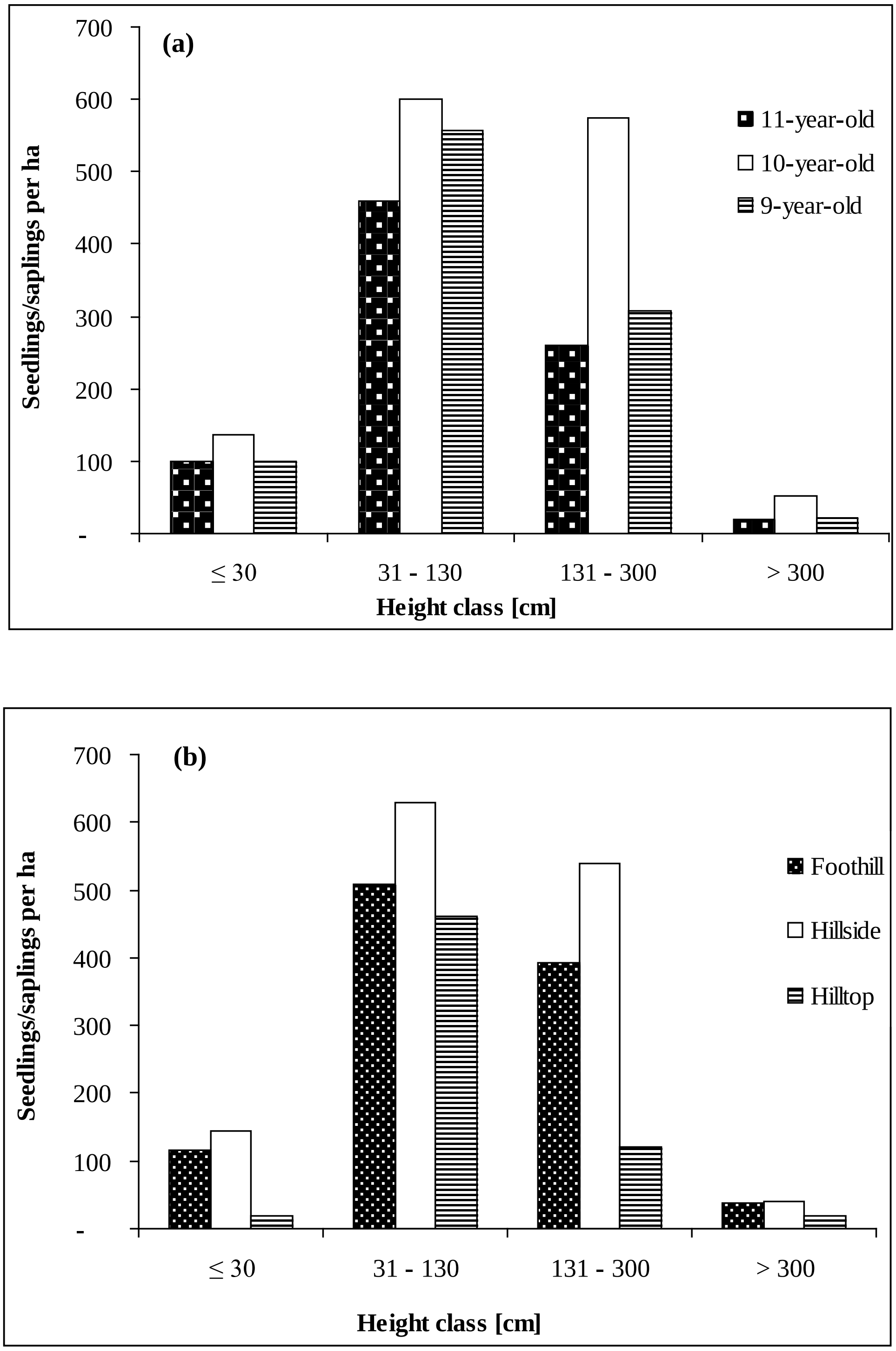
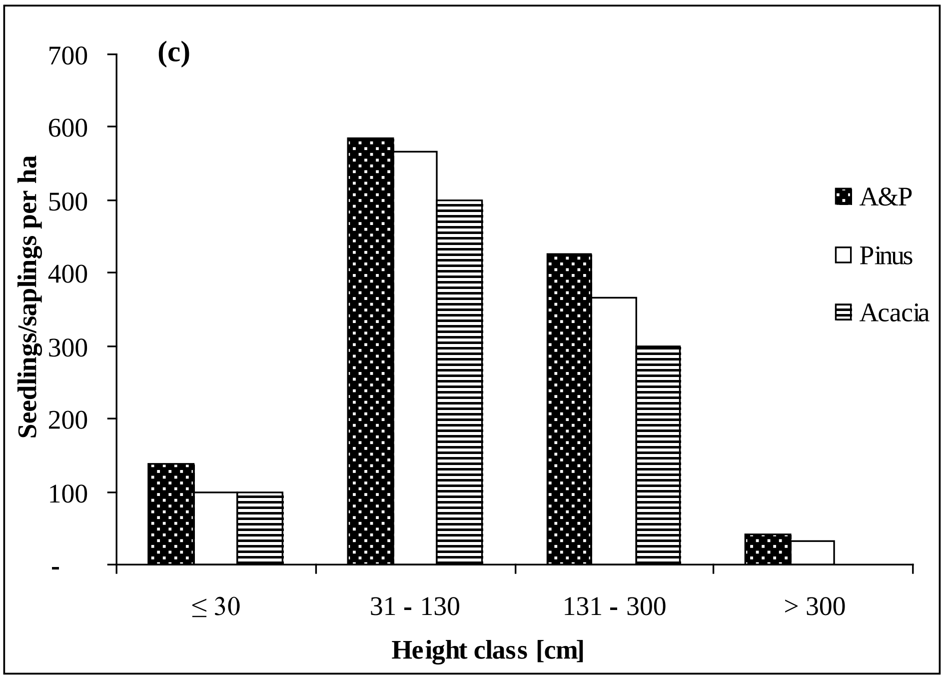


Fig. 18 Height distribution of indigenous regeneration species under forest plantation canopies in Luc Ngan District, Bac Giang Province, Vietnam. Based on 160 subplots of 25 m^2 (= 4,000 m^2):

(**a**) Various ages of mixed *Pinus massoniana* and *Acacia auriculiformis* plantation

(**b**) Various locations under ten-year-old mixed *Pinus massoniana* and *Acacia auriculiformis* plantation canopy



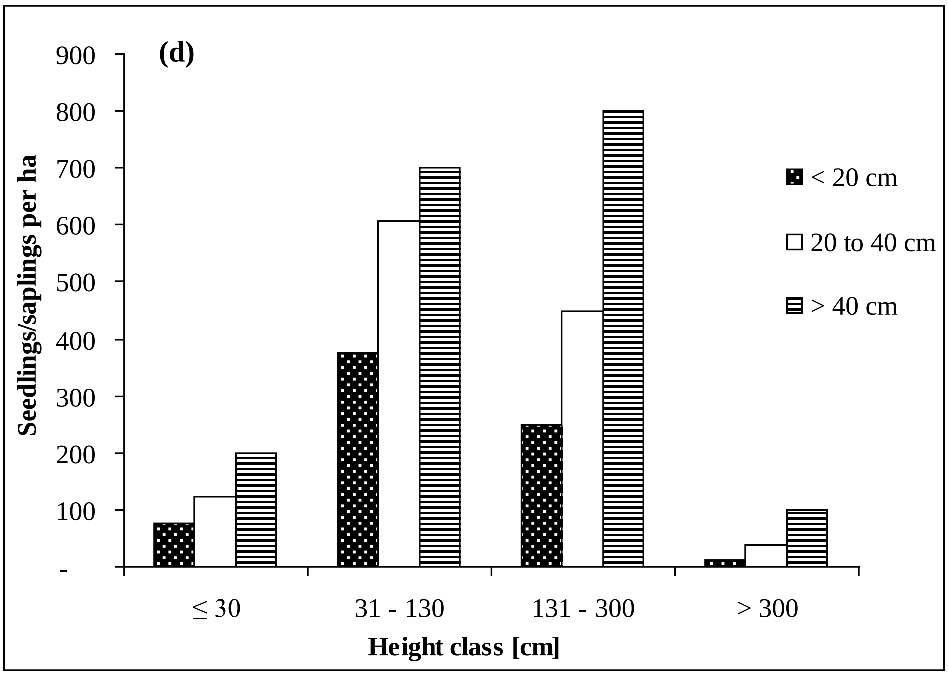


Fig. 18 (continued) Height distribution of indigenous regeneration species under forest plantation canopies in Luc Ngan District, Bac Giang Province, Vietnam. Based on 160 subplots of 25 m^2 (= 4,000 m^2):
(**c**) Type of ten-year-old plantations
(**d**)Various soil depths under ten-year-old mixed *Pinus massoniana* and *Acacia auriculiformis* plantation canpoy

The types of forest plantation also affect the regeneration of indigenous species. Fig. 18 (c) provides information about the density of seedlings in different plantation types. Micro-climate and site conditions in the mixed *Pinus massoniana* and *Acacia auriculiformis* plantations were the most appropriate to the regeneration succession, where a total of 584 and 425 seedlings were recorded in the height classes of 31-130 cm and 131-300 cm. More specifically, there were 567 and 367 seedlings in each height class in the *Pinus massoniana* plantation and 500/300 in the *Acacia auriculiformis* plantation. In contrast, the number of regenerated trees in all three plantation types was limited in height classes of < 30 cm and > 300 cm. These findings correspond to those found in the forest plantation stand, where the diameter and height increment grow faster in mixed *Pinus massoniana* and *Acacia auriculiformis* stands than in ones of other types. Ecological conditions under these stands are also better in comparison to others.

Fig. 18 (d) demonstrates the frequency of seedlings and saplings at different layers of the soil depth. This histogram rises from a height class of < 30 cm to 131-300 cm before decreasing suddenly in the height class of > 300 cm. The physical properties of the soil and its layer depth (O and A horizons) strongly influence the regeneration capacity of broad-leaved indigenous tree species. With a soil depth of >40 cm, the density of regeneration in the two height classes of 31-130 cm and 131-300 cm was 700 and 800 seedlings per hectare, respectively, whereas the soil layer depth from 20-40 cm only generated 375 and 250 trees per hectare.

In addition, the forest cover of the stands positively correlates to the diversity indices- that is, the higher the cover in the plantations, the higher the abundance and species richness of regeneration (Powers *et al.* 1997). The results show that a canopy closure ranging from 0.5 to 0.6 was quite suitable for natural regeneration. This is in accordance to Thuong´s study (2003) who stutied the influences of stand structure on natural regeneration. He stated that the optimal level of canopy closure for the growth and development of timber tree species varied from 0.6 to 0.7. Yuning *et al.* (2007), however, concluded that a crown closure ranging from 0.3 to 0.6 is the best for the optimal regeneration of Pine.

Discussion

With the soil covered by vegetation after planting, micro-climate and site conditions positively change, thus leading to the appearance of indigenous tree species in the plantation. In places where appropriate site conditions exist, light-demanding and fast-growing tree species can grow, creating a mixed stand that consists of both planted trees and regenerated indigenous species. Forest owners, especially those in remote and difficult-to-access areas, generally regard natural regeneration as the most interesting (MARD 2002).

Natural regeneration depends not only on available sources of seeds, but also on favourable ecological conditions concerning temperature, light, humidity, and soil types. The light plays the key role for the natural regeneration and succession, and it is thereby also one of natural regeneration´s limiting factors (Hale 2004; Benjamín 2009).

To promote natural regeneration under a plantation canopy, some silvicultural measures can be applied. These include: (1) cutting off all climbers that exist under the plantation canopy, (2) removing all non PCTs and diseased trees, and (3) removing the ground vegetation and weeds. On bare land, it is necessary to clear out all ground vegetation in order to create favourable conditions, strengthen light intensity on the surface, and help the seeds germinate. For plantations in which the number of regenerated (PCTs) is already sufficient, it is advisable to cut off all climbers, non-PCTs, and competitive trees to expand the nutritional space and improve the light conditions for the living trees.

3.1.5 Native shrub and ground vegetation under exotic plantation canopies

Shrubs

Twenty-five shrub species belonging to sixteen families were found in the research area with an average density of 3,930 stems per hectare. The results in Table 10 show that *Grewia paniculata* had the highest density, at 820 individuals per hectare. It was nearly double as high as *Cratoxylon pruniflorum* at only 500 stems/ha. However, the density of three species (*Morinda parvifolia, Rhodomyrtus tomentosa,* and *Breynia fruticosa*) was three times less than that of *Grewia paniculata*. This data indicates that the site conditions in the research area were suitable for the natural regeneration, growth, and the development of these species. They belong to families Tiliaceae, Hypericaceae, Rubiaceae, and Myrtaceae, which mainly consist of light-demanding and short-life pioneer species. According to Thai Van Trung (1970), they are normally adapted to poor site conditions, low organic matter, poor fertility, and acidic soil conditions.

Table 10 Shrub composition in forest plantation in Luc Ngan District, Bac Giang Province. Based on 160 subplots of 25 m^2 (= 4,000 m^2)

No	Species	Family	Density [n/ha]	Pecentage [%]
1	*Grewia paniculata*	Tiliaceae	820	20.9
2	*Cratoxylon pruniflorum*	Hypericaceae	500	12.7
3	*unknows species*		457	11.6
4	*Morinda parvifolia*	Rubiaceae	309	7.8
5	*Rhodomyrtus tomentosa*	Myrtaceae	289	7.3
6	*Breynia fruticosa*	Euphorbiaceae	240	6.1
7-25	Other species		1,316	33.6
	Total		**3,930**	**100.0**

The survey results also show that shrubs of ≤ 1.3 m in height accounted for 70 %. 25 % of shrubs layer were estimated to reach between 1.3 and 4.0 m tall, and only 5 % of the stems was > 4.0 m in height. Shrubs with good stem made up 72 %. Moderate and poor shrub stems accounted for 24 % and 4 % respectively.

It can thus be concluded that site conditions were quite suitable to the development shrubs under the plantation canopy. In order to promote the natural regeneration of the shrub layer, silvicultural measures can be applied to create favourable conditions for the growth and development of the shrubs.

Table 11 Species diversity of shrubs in different plantation ages, locations and plantation types in forest plantation in Luc Ngan District, Bac Giang Province, Vietnam

	Subplot [n]*	**Species richness** [mean ± SD]	**Density** [mean ± SD]	**Shannon index**	**Evenness index**
Plantation ages**					
Eleven-year-old	20	**9** ± 3.5	**800** ± 241	2.1	0.94
Ten-year-old	60	**21** ± 3.8	**2,360** ± 287	2.5	0.83
Nine-year-old	40	**23** ± 2.3	**3,920** ± 255	2.7	1.00
Locations**					
Foothill	40	**19** ± 3.6	**2,600** ± 261	2.5	0.93
Hillside	60	**24** ± 3.7	**2,800** ± 322	2.6	0.90
Hilltop	20	**16** ± 2.8	**2,910** ± 130	2.3	1.30
Plantation types***					
Pinus massoniana	12	**11** ± 3.1	**4,400** ± 370	1.9	1.39
Acacia auriculiformis	12	**6** ± 1.5	**2,160** ± 250	1.5	0.71
Acacia & *Pinus*	60	**24** ± 3.5	**2,910** ± 286	2.6	0.90

*subplot of 25 m^2 (5 m x 5 m); ** Mixed *Acacia auriculifomis* and *Pinus massoniana* plantation; *** Foothill and hillside locations

Table 11 shows that twenty-three shrub species dominated under the canopy of a nine-year-old plantation, and attaining both the highest density and the greatest amount of species diversity. The diversity indices were influenced by the locations. Hillside locations had the highest species richness and the greatest density compared to the other locations. These findings are identical to those in the research of natural tree regeneration under plantation canopies (Chapter 3.1.4). Also, the research results from the three plantation types show again that mixed *Acacia auriculiformis* and *Pinus* *massoniana* plantations had the highest levels of species diversity and density, as well as the strongest regeneration capacity.

The results also indicate that a forest canopy closure ranging from 0.5 to 0.6 was the most suitable for the growth and development of shrubs under the plantation canopy. This finding is in accordance with the research on the natural regeneration of indigenous tree species (Chapter 3.1.4), in that the succession of natural regeneration promotion will be met with more favourable conditions. Proper silvicultural measures should therefore be applied and aimed at regulating the canopy closure and contributing to the acceleration of natural regeneration under the plantation canopy.

Ground vegetation

The results reveal that the three species dominating the forest contributing to 85 % of the stand density (*Eupatorium odoratum* 40 %, *Euphorbia thymifoblia* 30 %, and Fern 15 %). The remaining of 15 % of the stand was divided among eight species: *Ageratum conyzoides, Amomun achinosphaera, Ipomoea batatas, Peperomia pallucida, Polygonum multiflorum, Pterocypsela indica, Thysanolanea maxima,* and unknown species. All stems had a good growth rate and mostly (70 %) good quality, and 25 % of moderate quality. According to Thai Van Trung (1970) and MARD (1996b), three of the above-mentioned species indicate favourable site conditions, with high contents of nutritents, humus, and a pH value ranging from 5 to 6. This proves again that site conditions are improved after planting, especially in places coverd by vegetation.

Table 12 Percentage of ground vegetation cover at various locations in Luc Ngan District, Bac Giang Province, Vietnam

Plantation types	[%]*	**Plantation ages**	[%]*	**Locations**	[%]*	**Soil depth**	[%]*
Acacia	15	Eleven-year-old	40	Foothill	45	<20	15
Pinus	25	Ten-year-old	60	Hillside	55	20-40	60
Pinus & Acacia	60	Nine- year-old	40	Hilltop	15	>40	60

(* vegetation cover)

The relationship between ground vegetation and plantation types is shown in Table 12. There we note that the highest cover of ground vegetations (60 %) was found under a ten-year-old and the mixed *Acacia* & *Pinus* plantation canopy. When comparing between the three locations (foothill, hillside, and hilltop), it becomes clear that the highest density of ground vegetation was on hillside locations (55 %). The densest ground vegetation (60 %) was also seen at locations where the soil layer depth (A & E) ranged from 20 to 40 cm.

As an overall conclusion, a close relationship between the site conditions, the upper story, the regenerated seedling layer, and the ground vegetation under the plantation canopy can be considered.

3.2 Natural forest assessment

3.2.1 Forest structure

Natural forests in Vietnam have a particularly high species diversity (FSIV 2005). In the tropical rainforest ecosytem, the existence of a species depends on its relationship to other species. It means that in addition to the competition for living conditions, a species will be directly or indirectly affected by its neighbouring species. Research on the relationship and interaction between species in the natural forest is therefore crucial important in order to adjust species components for planting purposes, particularly for species selection and planting methods.

Following Trung (1970), each species has an optimal ecological zone centre. The species´ stamina depends on their ecological amplitude, in that with either width or narrowness they can expand in their ecological zone. The environmentally adaptive ability is the highest in the centre of the ecological zone. If the tree species composition is more diverse, the ability to utilize the living space will be optimal. Under the same site condition, these species will then shape the conditions for the existence and development of other species. The object of the research is thus to find the distribution pattern of species in the natural forest. The results will contribute to propose the appropriate mixed planting method of indigenous tree species under a forest plantation canopy, as well as to the application of silvicutural measures.

The forest structure is the result of several factors, such as growth rates of various species, their light demands, the ecological conditions, the disturbance history, and management practice. A forest stand is commonly defined by the components of the trees, including height, diameter, crown layers, stems, shrubs, and herbaceous vegetation. Oliver and Larson (1990), however, defined forest stand structure as "the trees in a stand" and include the distribution of species in their description. Descriptions of forest stand structure are commonly based on the aggregation of individual plant measures (e.g. density, *dbh*, diameter distribution). The detailed results of this survey are based on the data of nine sample plots (18,000 m^2) and 894 trees with *dbh* ≥ 10 cm representing three forest types (Table 13).

Table 13 Density, species richness, mean and standard deviation of *dbh*, height and crown width (*CW*) of natural secondary forest in Xa Ly Commune, Luc Ngan District, Bac Giang Province, Vietnam. Following MARD (1984), $IIIA_1$ has a timber volume of 50 - 80 m^3/ha, $IIIA_2$ has one at 80 - 120 m^3/ha, and $IIIA_3$ is at 120 - 200 m^3/ha

Type of secondary forest	**Sample plot*** [n]	**Density** [n/ha]	**Species richness** [n/ha]	**dbh** [cm]	**Height** [m]	**CW** [m]
$IIIA_1$	3	447	29	**17.8** ± 6.5	**8.5** ± 7.8	**2.9** ± 1.4
$IIIA_2$	3	328	30	**19.2** ± 7.9	**10.5** ± 7.1	**3.6** ± 2.1
$IIIA_3$	3	715	36	**21.9** ± 1.6	**9.5** ± 2.1	**2.9** ± 1.4
Mean		**497**		**19.5** ± 3.8	**9.4** ± 4.2	**3.1** ± 0.7

*Sample plot of 2,000 m^2 (40 m x 50 m). dbh, Height, CW were calculated by arithmectic formula (Van Laar and Akca 1997).

According to MARD´s decision No. 682 B/QĐKT on the classification of natural forest (MARD 1984) dated to the 1st August, 1984, the category $IIIA_1$ has, as a result of over-exploitation and high-intensity selective logging, an estimated timber volume of 50 - 80 m^3/ha. The timber volume of the category $IIIA_2$ was estimated at 80 - 120 m^3/ha, and for $IIIA_3$ at approximately 120 - 200 m^3/ha.

Table 13 shows that the density of the forest category $IIIA_3$ was higher than in the other two categories, with 715 trees per hectare. A total of 36 species were found in the $IIIA_3$ category, while only 30 and 19 species were found in $IIIA_2$ and $IIIA_1$ categories, respectively. The mean *dbh* in $IIIA_3$ was also higher than in the either $IIIA_2$ or $IIIA_1$. Most natural forest areas were situated close to the villages, and were being over-harvested by famers living in the vicinity. Consequently, the natural forest had decreased in both quantity and quality. Based on the IUFRO classification (Leibundgut 1956), the vertical structure was categorised in different vertical stories as follows:

Upper story (tree height > 2/3 of top height): This is the highest layer, with the largest trees. It is dominated by a few light-demanding species, including *Liquidambar formosana, Schima wallichii, Albizia chinensis,* and *Elaeocarpus angustifolius*.

Middle story (tree height < 2/3 and > 1/3 of top height): High species richness and abundance were found. It was dominated by both light-demanding and opportunist species, including *Liquidambar formosana, Schima wallichii, Canarium album, Michelia mediocris*, *Illigera rhodantha*, *Quercus platycalyx*, *Machilus odoratissima, Cleistocalyx circumcissa*, *Wrightia annamensis*, *Symplocos laurina,* and *Toona sinensis.*

Lower story (tree height < 1/3 of top height): The lowest tree layer consisted of more shade-tolerant species and species shade-tolerant in their early phase, among them *Machilus odoratissima, Erythrophleum fordii, Wrightia annamensis, Anthocephalus indicus, Litsea cubeba, Miliusa balansae, Engelhardta chrysolepis, Alstonia scholaris, Cinnamomum obtusifolium,* and *Melanorrhoea laccifera.*

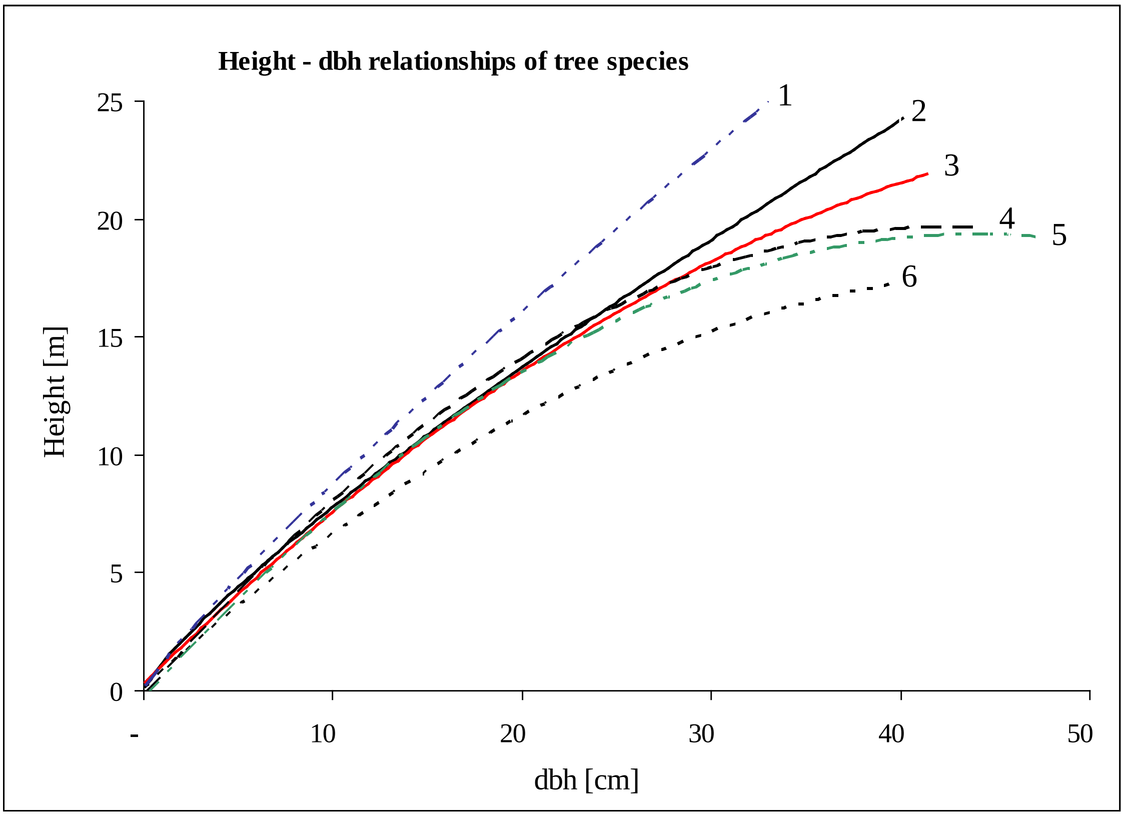


Fig. 19 Fitted height curves for some tree species in the natural forest in Xa Ly Commune, Luc Ngan District, Bac Giang Province. Based on nine sample plots of 2,000 m^2 (50 m x 40 m):

(1) *Canarium album;* fitted power equation:
$h = 1.187(dbh)^{0.817}$; $r^2 = 0.97$; n = 57

(2) *Lithocarpus ducampii;* fitted polynomial equation:
$h = -0.006(dbh)^2 + 0.793\ (dbh) + 0.306$; $r^2 = 0.83$; n = 41

(3) *Quercus platycalyx;* fitted power equation:
$h = 1.155\ (dbh)^{0.878}$; $r^2 = 0.93$; n = 32

(4) *Erythrophleum fordii;* fitted polynomial equation:
$h = -0.01(dbh)^2 + 0.937(dbh) – 0.233$; $r^2 = 0.85$; n = 56

(5) *Michelia mediocris;* fitted polynomial equation:
$h = -0.010(dbh)^2 + 0.899(dbh) – 0.391$; $r^2 = 0.84$; n = 50

(6) *Cinnamomum obtusifolium;* fitted polynomial equation:
$h = -0.007\ln(dbh)^2 + 0.724(dbh) + 0.130$; $r^2 = 0.97$; n = 44

Fig. 19 illustrates that six species show relatively steep height curves. The height curves of rapidly-growing tree species (*Canarium album*, *Lithocarpus ducampii*, and *Quercus platycalyx*) are clearly steeper than those of *Cinnamomum obtusifolium*, *Erythrophleum fordii*, and *Michelia mediocris.*

Table 14 The mean values of eight indigenous species in the natural forest in Xa Ly Commune, Luc Ngan District, Bac Giang Province, Vietnam which had been planted under forest plantation canopies. Based on nine sample plots of 2,000 m^2 (50 m x 40 m)

Species	**Density** [n/ha]	**dbh** [cm]	**Height** [m]	**CW** [m]
*Canarium album**	57	19.4	10.0	3.0
*Lithocarpus ducampii**	18	28.4	13.4	4.6
*Lithocarpus fissus**	23	23.8	11.9	3.5
*Cinnamomum obtusifolium***	44	17.0	8.3	2.7
*Erythrophleum fordii***	56	18.0	9.5	2.9
*Michelia mediocris***	50	22.7	11.0	3.5
*Machilus odoratissima **	44	18.7	9.8	3.0
*Quercus platycalyx**	32	18.4	9.1	2.7
Mean		**19.5**	**9.4**	**3.1**

(* light-demanding and ** opportunist species). dbh, Height, CW were calculated by arithmectic formula (Van Laar and Akca 1997).

A total of eight species were planted under the forest plantation canopy (Table 14). Most of them could be found in the middle story, with mean values in diameter and height which were higher than those of the hosting forest stand and dominated in upper storey. According to Chinh *et al* (1996), they are light-demanding species but still require shade in their young phase. On the whole, these species are suitable to plant under plantation canopies, and after five to ten years, the plantation canopies will gradually open depending on the biology of the species.

2.2.2 Density

The forest density is defined as the number of individual trees per hectare (Spurr and Barnes 1992). The average density of trees with a diameter of more than 10 cm was nearly 450 trees per hectare. The arithmetic mean diameter was 19.5 cm, the arithmetic mean height was 9.4 m, and the diameter of the crown was 3.1 m, with a total of 40 species found in the research area (Table 13). However, due to timber and fuel demands, the natural forest was declining in terms of both area and density via over-exploitation by the local people. Fig. 20 presents that most of the residual trees in the forest stands had a diameter of < 20 cm.

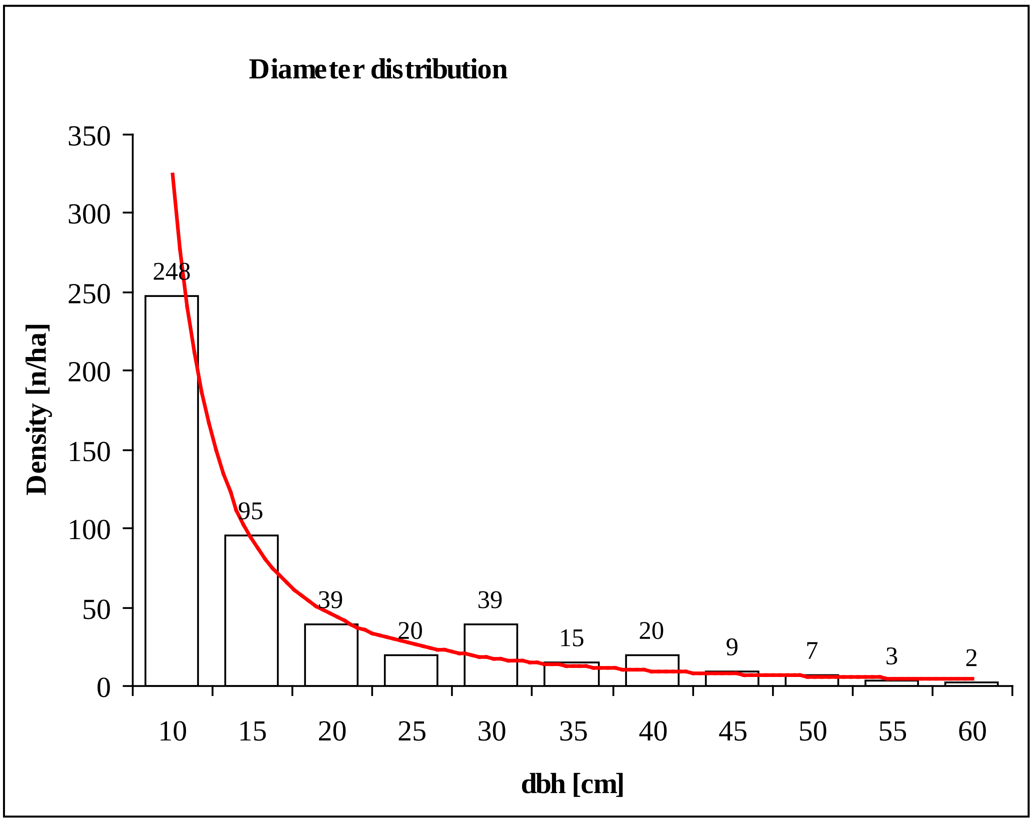


Fig. 20 Diameter distribution of tree species in the natural forest in Xa Ly Commune, Luc Ngan District, Bac Giang Province, Vietnam. Based on nine sample plots of 2,000 m^2 (50 m x 40 m), (mean *dbh* = 19.5 ± 10.8 cm; *n* = 497). Fitted power equation: $n = 324.21\,(dbh)^{-1.8036}$; $r^2 = 0.89$

3.2.3 Species composition and Importance Value Index (IVI)

The Importance Value Index was developed by Curtis and McIntosh (1951). It is calculated by relative abundance, dominance, and frequency of tree species in the forest. Dominance is calculated as the basal area of species, abundance as the number of individuals per species, and frequency by the occurrence of species in the sample plot. The Importance Value Index relative to this research is calculated as:

IVI = relative abundance + relative dominace + relative frequency (9)

where abundance = the number of individuals per ha

dominance = the basal area per ha

frequency = the percentage of subplots in which a given species occurred

Table 15 Abundance, dominance, frequency and Importance Value Index (IVI) on species level for all trees of *dbh* ≥ 10 cm in the natural forest in Xa Ly Commune, Luc Ngan District, Bac Giang Province. Based on nine sample plots of 2,000 m^2 (50 m x 40 m)

Rank	Species	Abundance [n/ha]	Dominance [m^2/ha]	Absolute frequency [%]	IVI [%]
1	*Liquidambar formosana*	54	3.7	100	37
2	*Schima wallichii*	64	2.6	89	33
3	*Canarium album**	32	1.2	100	20
4	*Michelia mediocris**	28	1.4	78	18
5	*Erythrophleum fordii**	31	0.9	100	18
6	*Machilus odoratissima**	38	0.6	89	17
7	*Aporusa tetrapleura*	32	0.9	78	17
8	*Persea velutina*	24	0.8	100	16
9	*Cinnamomum obtusifolium**	24	0.7	100	16
10	*illigera rhodantha*	10	0.7	89	12
11	*Quercus platycalyx**	18	0.6	78	12
12	*Lithocarpus fissus**	13	0.7	67	11
13	*Wendlandia paniculata*	14	0.5	67	10
14	*Anthocephalus indicus*	14	0.2	78	10
15	*Lithocarpus ducampii**	10	0.7	44	9
16	*Cratoxylon maingayi*	11	0.2	56	7
17-40	other 24 species	80	2.5	100	36
1-40	**Total**	497	12.2		**300**

Note: $\mathbf{IVI_i} = (n_i/\sum n_j \times 100) + (G_i/\sum G_j \times 100) + (f_i/\sum f_j \times 100)$; where **ni** is the stem number, $\mathbf{G_i}$ the basal area, and $\mathbf{f_i}$ the absolute frequency of species, $\mathbf{G_j}$, $\mathbf{n_j}$ and $\mathbf{f_j}$ are the total values of the stand.

* Species considered for local plantation programmes in Luc Ngan District, Bac Giang Province

Twenty-four families were found in the research area. Three families dominated in the natural forest, with Lauraceae occupying 17.4 % of species abundance, Theaceae (13.2 %), and Hamamelidaceae (11 %). Most of the species are light-demanding, and have high economic value due to their importance in furniture-making to the local people. Some of these trees, like *Schima wallichii, Machilus odoratissima, Canarium album, Erythrophleum fordii, Michelia mediocris, Cinnamomum obtusifolium, Persea velutina, Quercus platycalyx,* and *Lithocarpus ducampii,* have been then considered for local plantation programmes.

It is evident that *Liquidambar formosana* and *Schima wallichii* were the most important species in this area (Table 15). Both were of large size and dominated of the upper story. After Chinh *et al.* (1996), these are pioneer, light-demanding, and fast-growing tree species. Not only are they a successor after shifting cultivation that can grow and regenerate well in under severe site conditions (poor fetilizer, and dry/shallow soil), they have a good-quality timber, and are widely used for house material and furniture-making by the local people.

Seven species had an IVI between 15 and 20 (Table 15). Most of which are opportunist and shade-tolerant species, with the exceptions of *Canarium album* and *Machilus odoratissima*. These seven species dominated both the middle and lower stories. Some species such as *Canarium album, Michelia mediocris* and *Cinnamomum obtusifolium* have a high economic value for timber, resin, and fruits are also planted in household gardens. *Erythrophleum fordii* is classified as a hard timber species, often used in construction, ship-building, and furniture-making. With regard to Chinh *et al.* (1996) and Hung (2008), it is considered an opportunist species that requires shade when being young and becomes light-demanding when mature. It is a successor after *Liquidambar formosana* in the secondary succession process.

The results demonstrate that the site conditions are favourable for the growth and development of the mentioned species – it can also be said that the *study area in the Luc Ngan District is center of natural distribution of these species*.

3.2.4 Regeneration

Thirty-three regenerated species were found in the natural forest. The average density was 6,950 trees per hectare, of which 45 % had stems with mean height of more than 1.5 m greater than the mean height of the shrubs and ground vegetation. These species were not competed by the layer of shrubs and ground vegetations under the forest canopy. As a result, these species will become the PCTs and participate in main canopy layer.

Table 16 Density of regeneration species in the natural forest, in Xa Ly Commune, Luc Ngan District, Bac Giang Province. Based on thirty-six subplots x 25 m^2 = 900 m^2

No	**Species**	**Density** [n/ha]	**Relative abundance** [%]
1	*Machilus odoratissima**	1,440	20.7
2	*Schima wallichii*	864	12.4
3	*Ardisia crenata*	480	6.9
4	*Canarium album**	448	6.4
5	*Syzygium wightianum*	448	6.4
6	*Symplocos laurina*	352	5.1
7	*Unknow species*	192	2.8
8	*Miliusa balansae*	192	2.8
9	*Trema orientalis*	192	2.8
10	*Quercus platycalyx**	192	2.8
11-33	23 other species	2,150	30.9
	Total	6,950	100.0

(* Species were planted in local species trial)

As seen in Table 16, a total of ten regenerated species was found in the natural forest with a relative abundance greater than 2 %. Of those species, *Machilus odoratissima* presented the greatest relative abundance at 20.7 %, nearly double that of higher than *Schima wallichii* (12.4 %). The four following species (*Ardisia crenata*, *Canarium album*, *Syzygium wightianum* and *Symplocos laurina*) varied between 5 and 7 %.

The species composition between mature and regenerated trees is no significant diffirence. However, of the forty species in the upper story of the natural forest, only thirty-three regenerated species were found under the forest canopy. This indicates that the regeneration ability of some absent species was not realized potential. The Importance Value Index (IVI) shows that some species, among them *Liquidambar formosana*, *Michelia mediocris,* and *Erythrophleum fordii*, dominated in the upper canopy layer but were lacking in the regeneration layer. This is mainly supposed to be over-havesting by local famers, leading to a change in the micro-climate under the canopy which inhibits the germination and growth of some species. Additionally, some species in the families like Lauraceae, Burseraceae, and Fagaceae occurred more frequently than others, demonstrating that the site conditions were favourable for the growth and development of these species.

3.2.5 Associated trees

The composition of the plant community is partly determined by relationships among the plant components. If the plants can adapt themselves to the environment, they will grow and develop very well. Some species, however, have a negative effect on others, occasionally to such an extent that they become the exclusive plants in the natural forest. Therefore, research on the associated trees should have a significant role in forest rehabilitation, especially in the selection of species for mixed plantation methods.

The results of twenty-four temporary sample plots of 144 individual trees (see appendix 4) in three different forest types ($IIIA_1$, $IIIA_2$, and $IIIA_3$)[4] show that the associated tree was determined by appearance frequency. *Machilus odoratissima, Liquidambar formosana,* and *Canarium album* appeared more frequently in the natural forest, and all three are light-demanding species with a high ecomic value. The second group consisted of eight species: *Erythrophleum fordii*, *Cinnamomum obtusifolium*, *Cleistocalyx circumcissa*, *Trema orientalis*, *Wrightia annamensis*, *Schefflera octophylla*, and *Symplocos laurina*. This group included both opportunist and shade-tolerant species.

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[4] See in chapter 1.2.2

Two species (*Anthocephalus indicus* and *Michelia mediocris*) were found in the third group, and both of them are also opportunist and shade-tolerant species. These results are similar to those achieved by Trieu Van Hung (1993), who determined that in the natural forest, *Canarium album* was often found with species such as *Machilus odoratissima, Castanopsis sp, Peltophorum pterocarpum, Trema orientalis, Liquidambar formosana, Melia azedarach, Choerospondias axillaries,* and *Schima wallichii.*

3.2.6 Site condtions

Soil

The results of the soil analysis show that there was little difference in the soil´s chemical properties of the natural forest and a ten-year-old plantation. However, the soil in the natural forest was always deeper and has a lower stoniness ratio compared to the forest plantation.

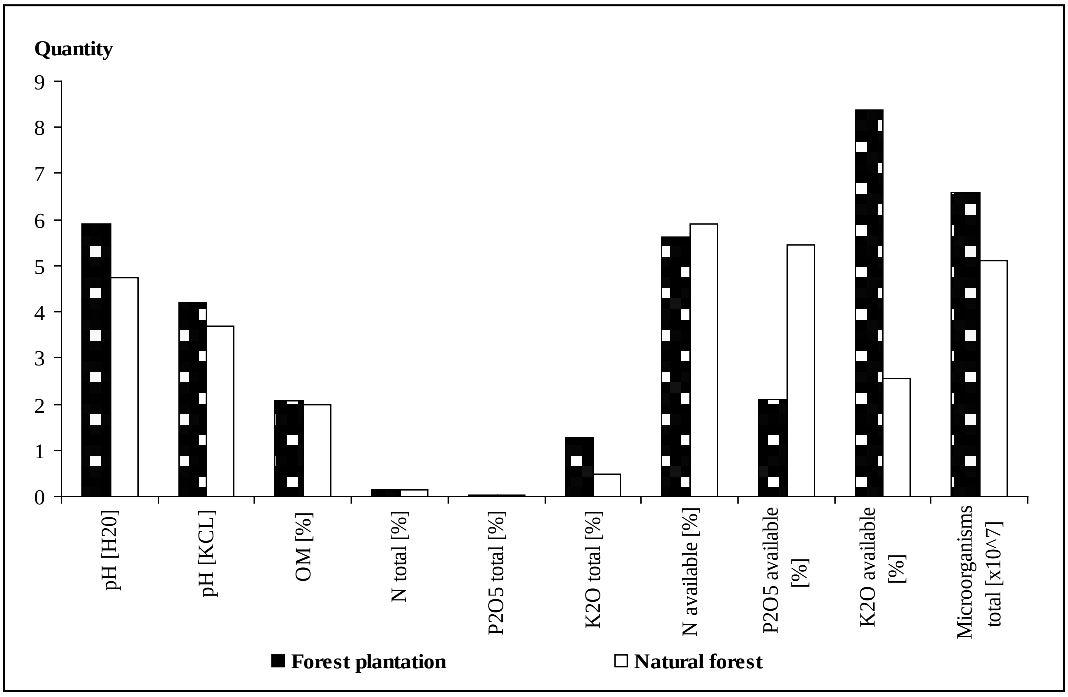

Fig. 21 Comparison of physical and chemical soil properties in natural forest and ten-year-old *Pinus massoniana* and *Acacia auriculiformis* plantation

Fig. 21 demonstrates that the hydrolytic acidity (pH_{H20} value) in the forest plantation was 5.9, compared to only 4.8 in the natural forest. The total and the available K_2O in the forest plantation were higher than in its counterpart. However, the available N and P_2O_5 in the natural forest were higher than in the forest plantation (Appendix 1). In order to fertilize the soil in the forest plantations, a fertilizer which contents high amounts of N and P_2O_5 should be applied to support the growth and development of the indigenous trees species.

Temperature

The results show that the average temperature at three positions within the forest (ground, 0.5 m, and 2.0 m) was 33.1°C, while that outside the forest was 35°C at the same time.

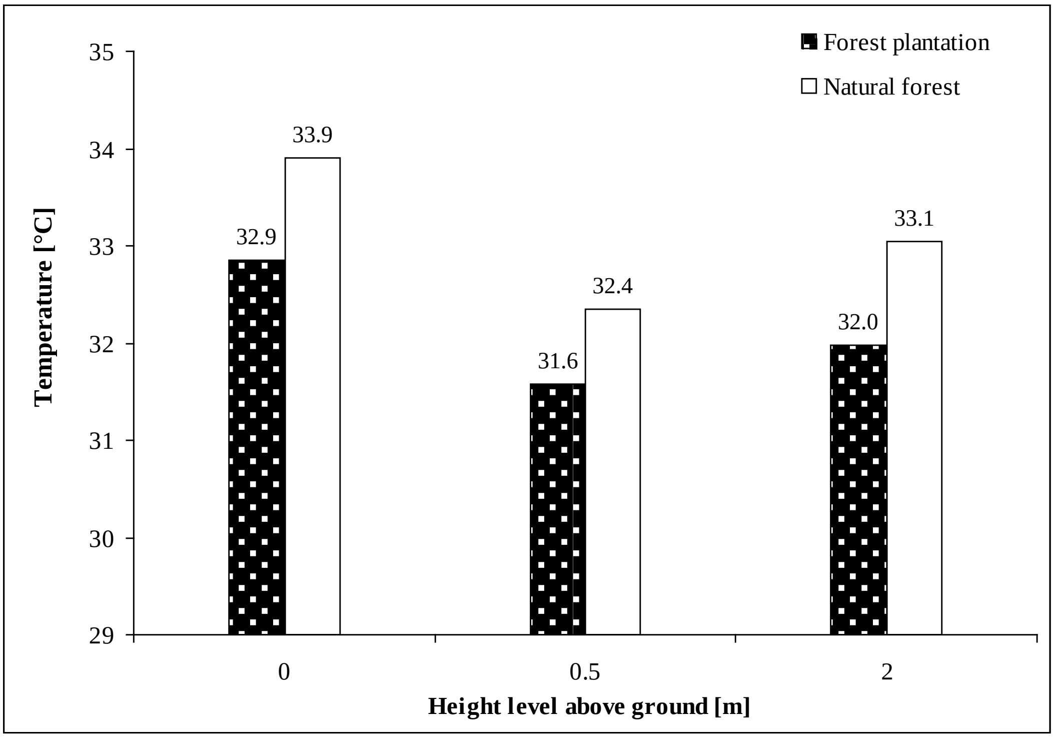

Fig. 22 Comparison of temperature at three different positions in the natural forest and forest plantation in Luc Ngan District, Bac Giang Province, Vietnam, recorded in July, 2007

The measure of temperatures within the forest did not find much of a difference between the average temperatures at the above-mentioned three positions. There was, however, a difference in those positions outside the forest, namely that the average temperatures on the ground was 37.4°C; 34.3°C at a height of 0.5 m, and 33.5°C at 2.0 m. The research did not find any noteable when comparing the temperatures between the natural forest and forest plantation (Fig. 22).

Air humidity

The results of the investigation demonstrate that air humidity was 59 % inside the forest and only 56 % outside it. There were additional differences in the air humidity at three positions within the forest – on the ground, humidity reached only 56 %, compared with 61 % and 60.5 % at 0.5 m and 2.0 m respectively. This shows that the forest canopy plays a vital role in prevention of the evaporation and preservation of air humidity under the forest canopy.

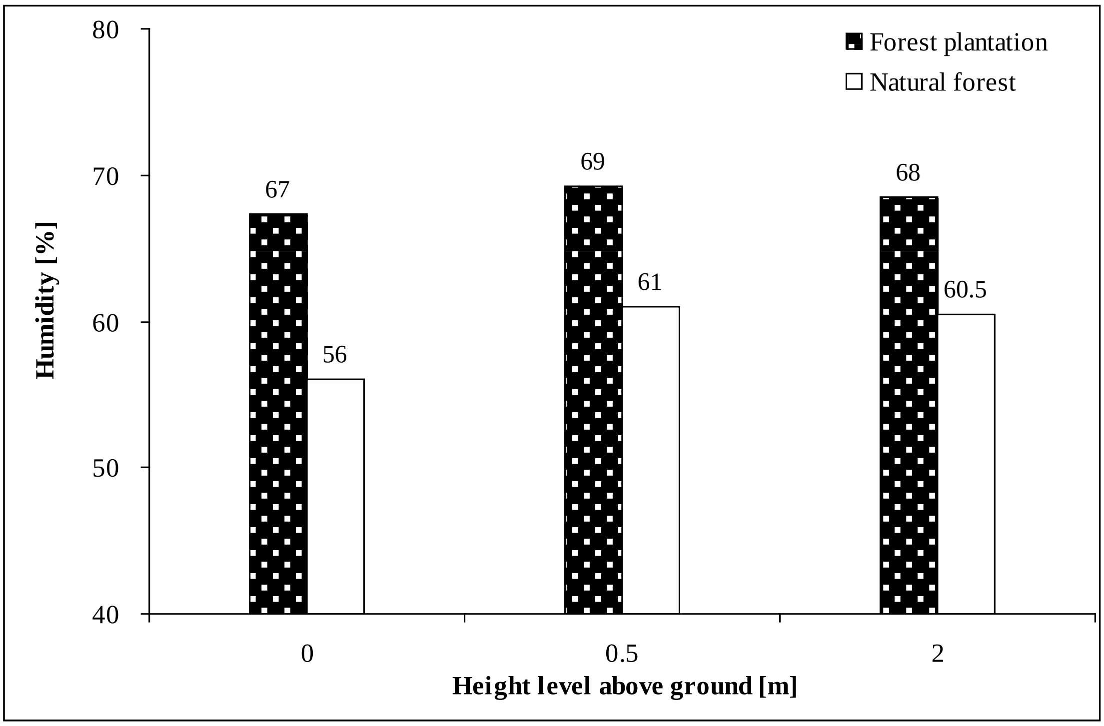

Fig. 23 Comparison of air humidity at three different positions in the natural forest and forest plantation in Luc Ngan District, Bac Giang Province, Vietnam, recorded in July, 2007

Fig. 23 illustrates that the humidity in the forest plantation was always higher than in the natural forest. This is primarily due to the crown being denser in the forest plantation than in the natural forest. Furthermore, the mean height of the forest plantation was lower than that of the natural forest, increasing the moisture retention of the forest plantation.

3.3 Local species trial assessment

3.3.1 Tree plantation development and status

With the support of the KfW_1 project[5], a few local species trials were set up in 2007. The intitial objective was to create mixed plantation stands of different ages in order to enhance the protective function of the plantation, create numerous products, and inhibit forest fires and diseases from pests. A total area of 29.50 hectares was selected at the foothill and hillside of Thuong B and Tu Tham Village, Dong Coc Commune and Vat Phu Village, Tan Hoa Commune. The average slope was less than 20° and the soil depth was more than 40 cm.

There are two criteria for selected species for planting in the research area (1) to grow and develop well in the natural forest, and (2) high potencial and adaptable regenetation in forest plantation. Furthermore, they had to play a crucial role in environmental improvement, conservation, and contribution to the development of forest resources. A number of nine indigenous tree species were selected for planting in 2007, including: *Quercus platycalyx*, *Lithocarpus ducampii*, *Michelia mediocrics*, *Machilus odoratissima*, *Erythrophleum fordii*, *Cinnamomum obtusifolium*, *Hopea odorata*, *Lithocarpus fissus*, and *Canarium album.*

Thinning techniques

According to Nguyen Ngoc Thuy (2006), five hectares of trial models were set up with three indigenous tree species (*Erythrophleum fordii*, *Mechilia mediocris,* and *Cinamomum obtusifolium)* under a fifteen-year-old *Pinus massoniana* plantation canopy in the Phuc Yen Town, Vinh Phuc Province. The mean diameter and height of the *Pinus massoniana* plantation were 15 cm and 10 m respectively. In order to find the most appropriate canopy closure for the growth and development of the indigenous species, three levels of canopy closure (0.3, 0.5 and 0.7) were experimented with. After three years, the results indicated that these species had the highest survival rate where the

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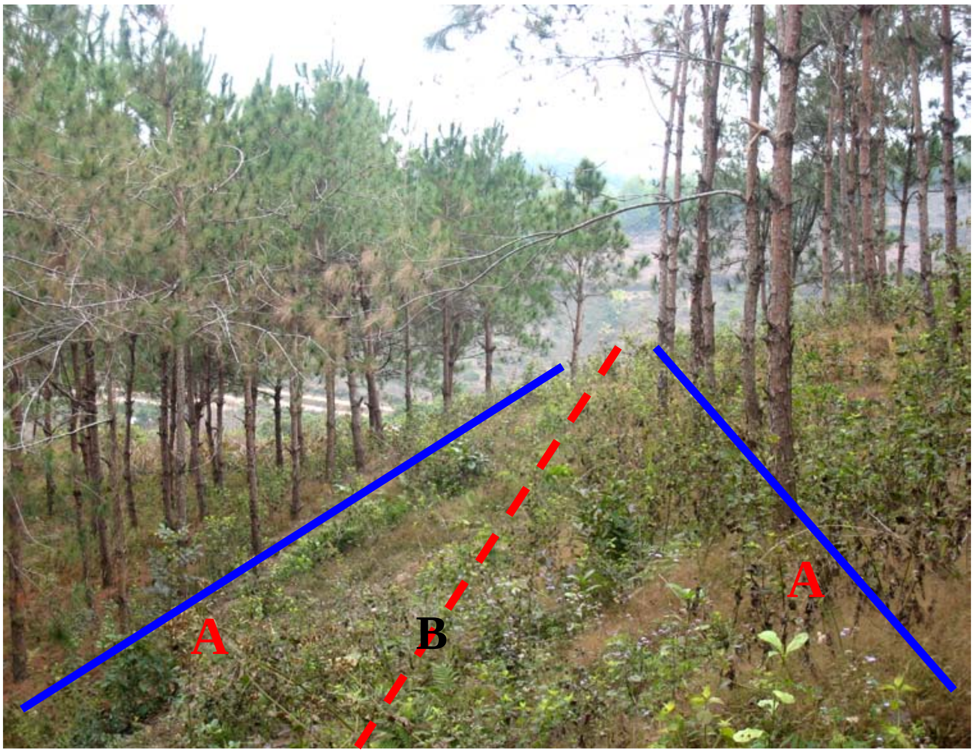
[5] Kreditanstalt für Wiederaufbau

canopy closure was 0.5, and the lowest the closure was 0.7. This finding was identical to that form Thuong´s study (2003) on the influence of stand structure on regeneration.



A	A	B	A	A	B	A	A
*	*	X	*	*	X	*	*
*	*	X	*	*	X	*	*
*	*	X	*	*	X	*	*
*	*	X	*	*	X	*	*
*	*	X	*	*	X	*	*
*	*	X	*	*	X	*	*
*	*	X	*	*	X	*	*
*	*	X	*	*	X	*	*
*	*	X	*	*	X	*	*
*	*	X	*	*	X	*	*

Fig. 24 Planting field (one removed tree line and two residual tree lines with a canopy closure of the forest plantation ≈ 0.3 - 0.4)

(A) ; * * * * * the residual tree lines

(B) ; X X X X X the removed tree line

The thinning intensity depended on the canopy closure of plantation varied between 30 and 40 %. After thinning the canopy closure was kept between 0.4 and 0.6. The strip cutting method was applied for the planting of indigenous species (Fig. 24).

Planting and tending technique

The planting density was 1,100 trees per hectare. Seedlings were planted in a triangular staggered spacing, and belts 2 m width were created for planting trees. Shrubs, grasses, and ground vegetation in the belts were removed before a hole sized 50 x 50 x 50 cm was dug in which to place the trees. A bed dressing application of Song Gianh organic manure was applied (1 kg per tree). Planting time ran from early May to the end of July in 2007. Container seedlings were mainly used for planting and *Fallopia japonica* species seeds were sown around the trees in order to maintain and improve the soil moisture and nitrogen fixation.

Table 17 Seedling criteria in the nursery for the established local species trials in Luc Ngan District, Bac Giang Province

No	**Species**	**Mean**		**Age** [month]
		drc* [cm]	Height [m]	
1	*Quercus platycalyx*	0.6	1.07	16
2	*Lithocarpus ducampii*	0.4	0.54	12
3	*Michelia mediocris*	0.4	0.52	18
4	*Machilus odoratissima*	0.8	1.05	18
5	*Erythrophleum fordii*	0.6	0.57	18
6	*Cinnamomum obtusifolium*	0.6	0.86	18
7	*Hopea odorata*	0.7	0.88	12
8	*Lithocarpus fissus*	0.5	0.78	12
9	*Canarium album*	0.7	0.82	12

(**drc*: diameter at root collar), source Dung *et al.* (2008)

Tending was done twice per year. The first tending was conducted one month after planting (September 2007), and included the replacement of failures and the application of fertilizer (NPK-5:10:3) at a total of 0.15 kg per tree. The second tending was carried out in November 2007. Subsequent tendings were implemented over the next three years (in March and November) and consisted of the replacement of failures and the break-up and pile-up of soil around the trees at a width of 60 cm and a depth of 3 - 4 cm. Protection against fire, grazing livestock, wild animals, insects, as well as competition against weeds, lianas, etc were annually implemented.

Table 18 Tree species, density and area in local species trial in Luc Ngan District - Bac Giang Province. (Planting density of indigenous species under plantation canopies was 1,100 trees/ha)

Commune	**Village**	**Upper story**		**Area** [ha]	**Blocks**
		Species	Density [n/ha]		
Dong Coc	Thuong B	Mixed *Pinus massoniana* & *Acacia auriculiformis*	1,000	20.0	H_1, H_2, H_3, H_4, G_1,G_2, G_3, K_1, K_2, K_3, K_4, I_1 and I_2
	Tu Tham	Pure *Acacia auriculiformis*	600	4.0	H_5 and C_1
Tan Hoa	Vat Phu	Mixed *Pinus massoniana* & *Acacia auriculiformis*	1,000	5.5	C_2 and D_1
	Total			**29.5**	**17 blocks**

(See detail in Appendix 2)

3.3.2 Growth and development of a local species in trials

Survival rate

The survival rate is a criterion to estimate forest quality. Furthermore, it reflects the adaptablility of the chosen species to its environment.

Table 19 Survival rate of all indigenous tree species in 17 blocks during the first three years, planted under the pure *Acacia auriculiformis* plantation and the mixed *Acacia auriculiformis* and *Pinus massoniana* plantation in Luc Ngan District, Bac Giang Province, Vietnam. Based on fifty-one temporary sample plots of 500 m^2 (20 m x 25 m)

Block	**1st year** [%]	**2nd year** [%]	**3rd year** [%]	**Block**	**1st year** [%]	**2nd year** [%]	**3rd year** [%]
H_1	98	96	88	**K_2**	92	88	76
H_2	99	96	89	**K_3**	98	97	84
H_3	99	93	73	**K_4**	97	98	88
H_4	100	96	91	**I_1**	98	94	87
H_5^*	99	99	80	**I_2**	94	98	89
G_1	99	97	83	**C_1^***	95	95	78
G_2	100	100	95	**C_2**	96	97	68
G_3	98	98	94	**D_1**	98	98	77
K_1	99	97	90				

Note: each block (see Appendix 2) was observed in three temporary sample plots of 500 m^2 (20 x 25 m) during the first three years
* Indigenous tree species were planted under the pure *Acacia auriculiformis* plantation canopy.

Table 19 shows that the overall survival rate of indigenous tree species was very high in 2008, ranging from 92 % to 100 %, but slightly reduced by about 1.3 % in 2009, with the exception of four blocks, G_2, G_3, H_5, and D_1. The highest reduction was recorded in block (H_3) (6 %). In 2010, the survival rate ranged between 68 % and 95 %. Block G_2 and H_4 had the highest rates, whereas block C_2 had the lowest.

Table 20 Survival rate of indigenous tree species planted in local trials during the first three year (from 2008 – 2010) in Luc Ngan District, Bac Giang Province, Vietnam. Based on fifty-one temporary sample plots of 500 m^2 (20 m x 25 m)

Species	**1st year** [%]	**2nd year** [%]	**3rd year** [%]
Quercus platycalyx	100	100	70
Machilus odoratissima	100	100	87
Hopea odorata	100	99	65
Michelia mediocris	100	98	93
Erythrophleum fordii	100	97	95
Cinnamomum obtusifolium	98	98	82
Lithocarpus ducampii	97	96	75
Canarium album	97	94	85
Lithocarpus fissus	93	91	40

Table 20 shows that the survival rate of planted species declined considerably three years after planting. Most species had a high survive rate in the first year, five species (*Quercus platycalyx*, *Machilus odoratissima*, *Hopea odorata*, *Michelia mediocris,* and *Erythrophleum fordii*) showed no mortality at all. The survival rate of species was slightly reduced by approximately 3 %, and less than 10 % in any case in the second year, and dropped dramatically in the third year. Most species kept to a survival rate over 85%, but the actual percentages ranged from 40 % (*Lithocarpus fissus*) to over 90 % (*Michelia mediocris*).

The results demonstrate that most site conditions were suitable for the growth and development of the chosen indigenous tree species. They confirm that local species trials have had some initial success and can be prosperous.

Diameter and height growth

Growth is the biological phenomenon of size increase over time, and is measured in diameter, height, basal area, and volume (Kyaw 2003). Information on diameter increments and growth patterns of individual trees is an important tool for forest management, primarily to: (i) select tree species for logging; (ii) select tree species for protection; (iii) estimate cutting cycles; and (iv) prescribe silvicultural treatments. In addition, *dbh* growth rate varies significantly between and within tree species, and also in relation to ages, seasons, and microclimatic conditions (Silva *et al.* 2002). Furthermore, the increment of the trees strongly depends on environmental site conditions, stocking of the stand, silvicultural treatments, and endogenous growth charateristcis of the species (Pancel 1993). Increment of diameter and height is a significant index in order to determine the growth ability of a species. This index can be applied to identify the best technical measurements in the forest, as well as to select the best species to improve the yield and quality of a forest plantation.

The results of 51 sample plots of 500 m^2 (20 x 25 m) in local species trials indicate that most of the species increased in both diameter at root collar (*drc*) and total height (*h*) after three years. The Mean Annual Increment of the diameter at root collar of species fluctuated between 0.9 and 1.4 cm (Table 21), while the Mean Annual Increment of total height (*h*) varied from 0.81 to 1.31 m (Table 22). These findings, taken together with the survival rates, confirm that the site conditions at the research area were suitable for the growth and development of these native species.

Due to the inadaptability of seedlings to a new environment after the first year planting, the mean increment of diameter at the root collar was only around 0.2 cm in 2008. This was more than doubled by 2009. By 2010, most of the species had a rapidly growing diameter of more than 1.5 cm. The seedling had developed a good adapted to the environment and absorb of nurtrients and minerals. Consequently, the growth rate of *Michelia mediocris* was the highest *drc* = 2.8 cm, followed by *Machilus odoratissima, Quercus platycalyx,* and *Erythrophleum fordii*. Other species had a mean diameter ranging between 1.0 cm and 2.0 cm.

There is a significant difference in the diameter increment and height growth between species. The height increment of species in 2008 was lowest, at only 0.2 m, while in 2009 it was more than one and a half times greater (around 0.49 m). Most the species grew rapidly in 2010, and four of them increased to more than 1.5 m. These were *Michelia mediocris*, *Lithocarpus ducampii*, *Machilus odoratissima*, and *Erythrophleum fordii* at 2.3 m, 1.99 m, 1.93 m, and 1.87 m respectively. Other species had a mean increment between 0.76 and 1.5 m.

Standard deviation of diameter and height of species in local species trial are calculated as (Kleinn *et al.* 2009).

$$S = \sqrt{\frac{\sum_{i=1}^{n}(Xi - \overline{X})^2}{n-1}} \qquad (10)$$

where S = standard deviation

$\overline{X}$ = estimated mean

Xi: = observed valued of i

n = number of tree in the sample

Table 21 Mean and standard deviation of tree diameter at root collar (*drc*) in local species trials planted 2007 in Luc Ngan District, Bac Giang Province. Based on fifty-one temporary sample plots of 500 m^2 (20 m x 25 m)

Species	drc [cm]			MAI
	2008	2009	2010	
Quercus platycalyx	**0.8** ± 0.1	**1.2** ± 0.4	**3.7** ± 1.2	1.2
Lithocarpus ducampii	**0.7** ± 0.1	**1.0** ± 0.3	**2.8** ± 1.2	0.9
Michelia mediocris	**0.7** ± 0.1	**1.3** ± 0.4	**4.1** ± 1.5	1.4
Machilus odoratissima	**1.0** ± 0.2	**1.5** ± 0.5	**4.0** ± 1.6	1.3
Erythrophleum fordii	**0.9** ± 0.2	**1.4** ± 0.6	**3.6** ± 1.3	1.2
Cinnamomum obtusifolium	**0.8** ± 0.1	**1.5** ± 0.4	**2.6** ± 1.3	0.9
Hopea odorata	**0.9** ± 0.2	**1.4** ± 0.3	**3.2** ± 0.8	1.1
Lithocarpus fissus	**0.7** ± 0.1	**1.3** ± 0.3	**3.2** ± 1.3	1.1
Canarium album	**0.9** ± 0.1	**1.6** ± 0.5	**3.4** ± 1.4	1.1

Table 22 Mean and standard deviation of tree height in local species trials planted 2007 in Luc Ngan District, Bac Giang Province. Based on fifty-one temporary sample plots of 500 m^2 (20 m x 25 m)

Species	Height [m]			MAI
	2008	2009	2010	
Quercus platycalyx	**1.30** ± 0.17	**2.00** ± 0.45	**3.43** ± 0.80	1.14
Lithocarpus ducampii	**0.89** ± 0.15	**1.20** ± 0.42	**3.19** ± 1.00	1.06
Michelia mediocris	**0.84** ± 0.11	**1.20** ± 0.51	**3.50** ± 1.40	1.17
Machilus odoratissima	**1.30** ± 0.18	**2.00** ± 0.43	**3.93** ± 0.90	1.31
Erythrophleum fordii	**0.88** ± 0.16	**1.31** ± 0.53	**3.18** ± 1.20	1.06
Cinnamomum obtusifolium	**1.09** ± 0.21	**1.50** ± 0.44	**2.43** ± 1.20	0.81
Hopea odorata	**1.22** ± 0.65	**1.53** ± 0.44	**2.99** ± 1.20	1.00
Lithocarpus fissus	**1.00** ± 0.19	**1.55** ± 0.24	**3.05** ± 1.20	1.02
Canarium album	**1.10** ± 0.17	**1.80** ± 0.49	**2.56** ± 1.20	0.85

Tables 21 and 22 indicate that the mean standard deviation (SD) of *drc* and height rose markedly in the three years between 2008 and 2010. One year after planting (2008), there was little deffirence in the SD of both diameter and height between species, with the single exception of *Hopea odorata* – the SD was more than three times higher by

2009. The SD in 2010 went up approximately ten times in comparision to 2008. Some species, for example, *Michelia mediocris*, *Machilus odoratissima* and *Canarium album*, had a high SD of diameters at 1.6 cm, 1.5 cm, and 1.4 cm respectively. This was mainly due to a significant difference in diameter and height growth rates between the individual trees three years after planting. Field observations revealed that the growth rate of individual trees planted in severe conditions (shallow and dry soil, light shortage) was very low.

In summary, three years after planting, four species ferformed a generally high survival and growth rate in diamter and height, namely *Erythrophleum fordii*, *Michelia mediocris*, *Machilus odoratissima* and *Canarium album*. In contrast, five other tree species had a slow growth rate: *Lithocarpus ducampii*, *Quercus platycalyx*, *Hopea odorata*, *Cinnamomum obtusifolium* and *Lithocarpus fissus*.

Quality of local species trial

The quality of individual tree is a significant criterion which reflects the adaptability of a species to a specific site condition. Tree quality is normally determined by the percentage of good, moderate, and bad trunk, braches, and crown qualities. It is additionally used to select the best technical silviculture treatments to both improve the yield and quality of plantation stands and choose the most suitable species for each site condition.

In Table 23, it can be seen that the forest plantation in 2010 was of high quality, with more than 90 % of the stems classified as "good". *Quercus platycalyx* and *Michelia mediocric* had the highest quality, at 99 %, while *Canarium album*, *Lithocarpus ducampii*, and *Lithocapus fissus* had the lowest qualities (85 %, 84 %, and 82 %, respectively). The tree quality in each block was generally identical. However, the H_2, H_4, G_1, and G_2 blocks in Thuong B Village and the D_1 block in Vat Phu Village had much better tree qualities (more than 95 %) than the other blocks.

Table 23 Quality assessment of indigenous tree species in three years 2008 – 2010 in local species trial in Luc Ngan District, Bac Giang Province. Based on fifty-one temporary sample plots of 500 m^2 (20 m x 25 m); all data in %

Species	**2008**			**2009**			**2010**		
	[G]	[M]	[B]	[G]	[M]	[B]	[G]	[M]	[B]
Quercus platycalyx	97	3		99	1		99	1	
Lithocarpus ducampii	76	14	10	89	6	5	84	10	6
Michelia mediocris	99	1		99	1		99	1	
Machilus odoratissima	97	3		98	2		97	3	
Erythrophleum fordii	89	11		92	8		91	9	
Cinnamomum obtusifolium	92	8		94	6		92	8	
Hopea odorata	99	1		99	1		98	2	
Lithocarpus fissus	84	14	2	90	7	3	82	10	8
Canarium album	90	8	2	89	8	3	85	12	3

(**G**: good; **M**: moderate; **B**: bad. According to MARD standard (2004b): **good** quality tree is a vigourous, high growth rate in both diameter and height, straight stem, and disease-free; **moderate** quality tree has a straight stem, slow growth rate; **bad** quality tree has a crook stem, very slow growth rate, and disease).

In general, site conditions are favourable for the growth and development of the studied species. Three years after planting, four species (*Erythrophleum fordii*, *Michelia mediocris*, *Machilus odoratissima* and *Canarium album*) had a generally high survival and growth rate in diameter and height as well as the tree quality.

4 Silvicultural conclusions and recommendations

4.1 Criteria for the selection of promising indigenous species

Natural regenetation of indigenous tree species under plantation canopy with height of more than 1.5 m. Each species has an interactive on relationship among forest populations. If the height of a particular species is higher than that of other species, those will not be competed by others and conversely (MARD 1996a; FSIV 2005). The results of native shrubs and ground vegetation in the forest plantations (chapter 3.1.5) indicate that the average height of the shrubs was 1.3 m; thus, tree species with a height of more than 1.5 m will not be competed by the shrubs and ground vegetation.

Species with a relative abundance of higher than 5 % under the forest plantation canopy: if any species has a higher frequency of natural regeneration (seedlings and saplings), their adaptation capacity is recognized as markedly higher than that of other species (Pancel 1993; Richards 1996).

In the local specie trial, species with survival rate greater than 85 % three years after planting. Survival rate is a criterion to estimate the adaptability of species to their environments and evaluate the stand qualities. According to the regulations of MARD (Binh *et al.* 2004b), the survival rate of a forest plantation three years after planting should be at least 85%.

Mean Annual Increment (*MAI*) of a species in the local species trial, greater than 0.9 cm in diameter and > 0.8 m in height during the first three years. The increments of diameter and height are a significant index in order to determine the growth ability of species and quality of the forest plantation. The increments of the trees futher depend on the site conditions and endogenous growth characteristics of the species (Pancel 1993). However, the purpose of the research is to transform plantation stands into close-to-natural forests within a forest cycle of 50 years.

Based on the chosen criteria, four species, namely, *Canarium album, Erythrophleum fordii, Cinnamomum obtusifolium*, and *Michelia mediocris* are recomended for planting.

4.2 Criteria for the selection of appropriate planting sites

Sites at foothill position under a mixed *Acacia* & *Pinus* plantation canopy, with depth of soil layer more than 50 cm.

As mentioned in Chapter 3.1.1, the analysis carried out in the three plantation types shows that mixed *Acacia* & *Pinus* stands had the highest level of diversity and density, as well as the strongest capacity to naturally regenerate woody seedlings, shrubs and ground vegetation under the plantation canopies. This is similar to research carried out by Carnevale *et.al* (2002) on native species regeneration under mixed and pure plantations, where there was a greater abundance of individual and species diversity in the mixed plantations than in their pure counterparts. In addition, Guariguata (1995) and Montagnini (1999) reported that mixed species plantations promoted a greater diversity of regeneration in their understories than pure species plantations. These findings were similarity to those in the study of forest plantation stands (Chaper 3.1.1). Diameter and height increments of mixed *Pinus massoniana* and *Acacia auriculiformis* stands were greater than in other stands. Furthermore, the ecological conditions under these stands were better in comparison to others.

A comparison of physical and chemical soil properties at three locations (foothill, hillside, and hilltop) under plantation canopies indicated that soil fertility (OM, N, K_2O, and microorganisms) at foothill positions was the highest. The soil humidity was also highest at the foothill locations, and it can thus be concluded that the foothill areas are the best for the growth and development of indigenous species.

Site with a soil depth > 50 cm. This follow Pancel (1993), who stated that polyethene containers of 15 cm in length were best for the root collar diameter growth of seedlings in regions with abundant rainfall. A planting pit sized 50 x 50 x 50 cm was suitable for absorbing the nutrients and the humidity requirement of indigenous species during the first three years after planting (MARD 1996b). On the other hand, fertile soil and a high diversity of native regeneration species were always found in locations where the depth of the soil layer was > 50 cm. Thus, only sites where the depth of the soil layer is > 50 cm are suitable for the growth and development of indigenous seedlings.

The shade index positively correlated to the diversity indices: shadier plantations had a higher abundance and species richness (Powers *et al.* 1997). Other authors also reported that the canopy closure of the forest stand directly influenced the density and vitality of the seedlings (Yanes and Smith 1982; Oliver and Larson 1996). The results show that a canopy closure ranging from 0.5 to 0.6 is suitable for the natural regeneration of woody seedlings and shrubs under the plantation canopy. This is in accordance with Thuong (2003), who studied the influences of stand structure on natural regeneration. In his research, he found that the optimal level of canopy closure for the growth and development of timber tree species varied between 0.6 and 0.7. Another study by Yuning *et al.* (2007) indicated that a crown closure of 0.3 to 0.6 had the best regeneration of Pine. The specific biological characteristics of the indigenous tree species in the research area show that most of them are light-demanding species when mature (FIPI 1996), but they require shading in their young phase due to their fragility (FIPI 1996; Hung 2008). Accordingly, stand conditions with a canopy closure of 0.5 – 0.7 are selected as the most favourable.

Places where *Eupatorium odoratum*, *Euphorbia thymifoblia*, and fern species grow well in the ground vegetation. According to Thai Van Trung (1970), these species are indicators of good site conditions, with high contents of nutritients, humus, and a pH values ranging from 5 to 6 (Trung 1970; MARD 1996b). Also, according to FIPI (1996), pH values between 5 and 6 is the most suitable to the growth and development of indigenous species.

4.3 Planting methods

Some species, however, may have a negative effect on others, some to such an extent that they become the exclusive plants in the natural forest. In addition, if two species are growing next to each other and have the same demand for nutrients, light, and water, they will compete for it and may restrain each other´s growth (Them 1992). Based on the point-to-tree distance sub-sample plots, this can suggest a need for mixed planting methods.

If the tree species composition is more diverse, the ability to utilize the living space will be optimised. Mixed tropical rain forests are divided into five strata, the tree strata (A, B, and C) and the herbaceous strata (D and E) (Richards 1996). The highest stratum (A) is dominated by light-demanding species, while the middle strata (B and C), by opportunist and shade-tolerant species. Therefore, light-demanding, opportunist, and shade-tolerant species should be combined when creating mixed forest plantations in order to increase their protection functions as well as the diversity their production functions.

The following mixed planting methods of indigenous species under a forest plantation canopy are recomended:

Canarium album + *Erythrophleum fordii* + *Michelia mediocris* = 3+2+1

Canarium album + *Erythrophleum fordii* + *Cinnamomum obtusifolium* = 3+2+1

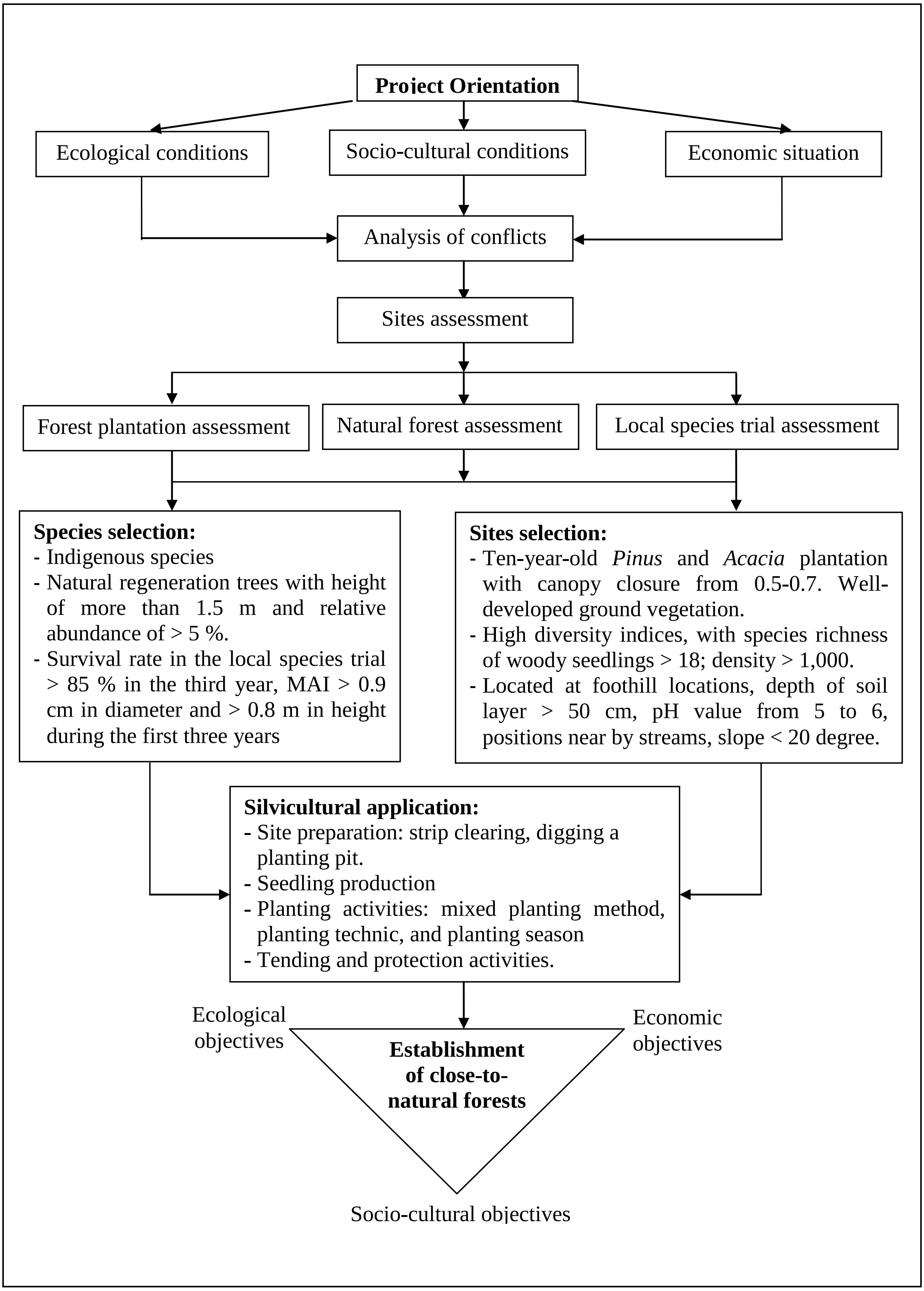


Fig. 25 Silvicultural approach for transforming pure plantation into mixed plantation in Luc Ngan District, Bac Giang Province, Vietnam

4.4 Recommendations

Based on the research results on natural regeneration of indigenous species under plantation canopies, the growth and development of trees in local species trials, and the characteristics of natural forests, the following recommendations can be given:

Table 24 Development of a single-species plantation towards close-to-nature forests

Time schedule	Operations	Activities and explanations
Et – 18 months	Seedling production in nursery	- four indigenous tree species: *Canarium album, Erythrophleum fordii, Cinnamomum obtusifolium,* and *Michelia mediocris* Seedling criterion: - Diameter at root collar >1 cm; height > 1.5 m; - age > 18 months and disease free. Mycorrhiza fungi should be present.
Et – 6 months	Selection of stands for underplanting	- *Pinus massoniana* or *Acacia auriculiformis* plantation stands about ten to fifteen-years-old; - density ≈ 1,000-1,300 trees per ha; - canopy closure ≈ 0.5 – 0.7; - well-developed ground vegetations. Plantation stand criterion: - *dbh* ≈ 10 – 15 cm; - Height ≈ 7 – 10 m. Soil criterion: - soil depth > 50 cm, developed on Schist; - pH value ≈ 5.0 – 6.0; - layer depth of OM > 10 cm; OM > 5 %. Site criterion: - positions near streams or below hillside locations with high moisture levels in the soil and a slope > 20 degree

(Continued)

Et – 4 months	Strip clearing	- cutting method will be applied by cutting one tree line and two residual tree lines with a canopy closure in forest plantation ≈ 0.4 to 0.6
Et – 2 months	Weeding	- removal of shrubs, wild grasses, and vegetation on strips
Et – 1 month	Digging a planting pit	- planting pit sized of 50x50x50 cm
Et – 0.5 months	Filling holes and bed dressing fertilization	- bed dressing: Song Gianh organic manure, 1kg per tree; - must be completed ten days before planting.
Et	Planting indigenous species	<u>Planting season:</u> - from early May to the end of July <u>Planting density:</u> - 555 trees per ha, spacing of 9 m x 2 m <u>Mixed planting method:</u> +*Canarium album* + *Erythrophleum fordii* + *Michelia mediocris* = 3+2+1 (n = 555 trees per ha); or +*Canarium album* + *Erythrophleum fordii* + *Cinnamomum obtusifolium* = 3+2+1 (n = 555 trees per ha); or +*Canarium album* + *Michelia mediocris* + *Erythrophleum fordii* = 3+2+1 (n = 555 trees per ha); or +*Canarium album* + *Cinnamomum obtusifolium* + *Erythrophleum fordii* = 3+2+1 (n = 555 trees per ha).
Et + 1 month	Replacement of failures	- one month after planting
Et + 3 to Et + 39 months	1) Tending operation biannually	- the first time tending should be carried out three month after planting, main operation is the replacement of failures; - the second tending measure includes the replacement of failures, break-up and pile-up the soil around the tree with a width ≈ 60 cm and a depth ≈ 3 - 4 cm.

(Continued)

	2) Fertilizer application 3) Pruning	- top dressing by Lam Thao fertilizer (NPK) will be applied 0.15 kg per tree at the second tending. - pruning of upper story if affecting to indigenous species; Protection against fire, grazing livestock, wild animals, insects etc., as well as against competition by weeds, lianas, and the like.
Et + 4 to 50 year	Protection	- protection, pruning, and thinning
Et + 20 years	Harvesting exotic species	- Selected logging method will be applied
Et + 50 years	Harvesting indigenous species	- Clear cutting method will be applied

Et = the time of planting

This management scheme is used to transformation of forest plantation in to close-to-natural forest with the forest cycle of 50 years.

5 Summary

In Vietnam, the natual forest cover in recent years has been declining significantly. According to MARD (2004), 43 % of Vietnam was covered by forest in 1945. This figure dropped, however, to 30 % by 1976 (Thao 2011) and 28 % by 1996 (FIPI 1997; Trung 1998; FAO 2011). The main causes of this decrease were the over-exploitation of forest resources, shifting cultivation, the conversion of natural forest to coffee and rubber plantations, grazing, and illegal logging (WCMC 1994; Hoang 2005; Thao 2011). Since 1992, the Vietnamese Government has begun enacting numerous policies, programmes, and projects with the intention of accelerating forest rehabilitation (MARD 2004), but almost all of the established areas are pure plantations with exotic tree species like *Acacia* and *Pinus*. In order to increase forest functions, such as the protection of critical watersheds, soil conservation, and the delivery of social benefits to rural farm households, silvicutural treatments should be applied to transform pure exotic plantation into mixed plantation. However, the following questions arise when the issues of silvicutural treatments are considered:

- On which sites a transformation could be promising?
- Which kind of indigenous species could be suitable to a particular planting site?
- Which kind of silvicultural treatments can be applied?

In order to answer these questions, the research has focused on the same ecological factors, soil dynamics, natural regenegation of indigenous trees under plantation canopies, and biological charateristics of some indigenous tree species in natural forest and local species trials.

The research was carried out in Phu Nhuan, Dong Coc, and Tan Hoa Communes, located in Luc Ngan District, Bac Giang Province. The research area spreads into the climatic region of northeastern Vietnam, characterized by a tropical monsoon climate with an average annual temperature of 24°C, an average relative humidity of 81 %, and an average annual rainfall of 1,450 mm (Anonymous 2006; 2011). Most of the research area is covered by the light-yellow Ferralsols soil group (FAO 1988), which has developed on granite and sandstone.

The forest plantation of this research was established between 1996 to 1998 and supported by the "KfW1 Project"[6]. A total of 2,370 hectares of *Pinus massoniana* and *Acacia auriculiformis* plantations was planted on degraded land (Apel 2000) in order to contribute to the improvement of the ecological conditions and the local people's livelihood (MARD 1995a). At present, these stands are growing and developing well. The micro-climate created under the plantation canopy has been improved, and some indigenous species are being regenerated under those same canopies.

To assess the forest plantation, forty temporary sample plots (20 x 25 m) were designed. These were laid out systematically through the area on a gridline of 500 x 500 m with one random starting plot. In these plots, all trees with their diameter with a breast height of ≥ 5 cm were measured and recorded; four subplots of 25 m^2 (5 x 5 m) located at the four corners of each sample plot were used to investigate the shrubs, ground vegetations, and natural regeneration of woody tree species (seedlings and saplings) with a *dbh* < 5; four quadrates of 1m^2 each were also established at the four corners of each subplot in order to measure the litter layer. A total of thirteen soil profiles represented three locations (foothill, hillside, and hilltop), and the ages of the forest plantation was dug at the centre of thirteen selected sample plots in order to identify the physical and chemical properties of soil. The humidity and temperature elements under the forest canopy were defined at each of the sample plot and outside the forest using electronic-sensor equipment. Measurements were conducted at 9:00 a.m, 9:30 a.m, and 10:00 a.m at three positions (on the ground, at 0.5 m and 2.0 m above ground).

To assess the natural forest, nine sample plots of 2,000 m^2 (40 x 50 m) representing three forest types were set up at Xa Ly Commune. In these plots, all tree species with a *dbh* of ≥ 10 cm were measured and recorded. Four subplots of 25 m^2 (5 x 5 m) were set up in four corners of the sample plots to record the regeneration of woody species. In order to determine "associated trees," which usually grow near each other in the natural

[6] Kreditanstalt für Wiederaufbau (Germany)

forest, a total of twenty-four point-to-tree distance sub-sample plots was established. Six tree species which are the nearest to the centre of the sample plots with a *dbh* of ≥ 10 cm were were also investigated. To examine soil nutrients, one soil profile was dug at the centre of a sample plot. Humidity and temperature elements beneath the forest canopy were also determined by using methods applied to the forest plantation.

To evaluate the growth of indigenous tree species in the local species trial, fifty-one temporary sample plots of 500 m^2 (20 x 25 m) were randomly set up. Survival rate, diameter at root collar (*drc*), total height (*h*), and the vitality of the trees were measured and recorded in three consecutive years (2008-2010).

The following key results were obtained:

(1) The relationship of *dbh* and total height of *Pinus massoniana* and *Acacia auriculiformis* species are close. The diameter distribution of *Pinus massoniana* stands focuses mainly on the classes from 8 – 10 cm, indicating that the plantations are at young stage and they have no strong competition among individual trees for living space. The mean growth of *dbh* and total height of trees at the hillside location is the highest compared with foothill and hilltop locations (chapter 3.1.1).

(2) During a ten year-period (1997 to 2007), leaf litter accumulated to more than 12 cm thickness. Soil porosity increased gradually in spots covered by vegetation while soil density gradually decreased. The organic matter (OM) increased from 1.5 % to 2.1 %, and the number of micro-organisms increased strongly from 1.67 x 10^7 to 6.58 x 10^7 per 100 g of soil sample (chapter 3.1.2).

(3) A ten years after the establishment of the forest plantation on bare hill, both the physical and chemical properties of the soil were positive change. Soil fertility at foothill locations was quite favourable and appropriate for indigenous tree species. Silvicultural treatments can be applied on some suitable site conditions in order to transform pure plantations into mix-plantations.

(4) Whithin the forest plantation, the temperature and humidity at three positions (ground, 0.5 m, and 2.0 m above the ground) are not markedly different. However, there is a significant difference outside the forest (chapter 3.1.3).

(5) The site conditions under forest plantation canopies are suitable for the natural regeneration of indigenous tree species. The ten-year-old plantation shows the greatest diversity (species richness of 20 and Shannon index of 2.4), compared with nine and eleven-year-old plantations.

(6) Native species diversity found at the hillside position is higher than that of in foothill and hilltop positions, with a species richness of 19 and Shannon index of 2.4. Species diversity under mixed *Pinus massoniana* and *Acacia auriculiformis* plantation canopies is higher than other types of plantation (species richness of 18 and Shannon index of 2.3).

(7) The frequency of six regenerated indigenous species (*Litsea glutinosa*, *Wrightia annamensis*, *Erythrophleum fordii*, *Canarium album*, *Michelia mediocris*, and *Cinnamomum obtusifolium*) under a plantation canopy is higher than others species. Canopy closures varying from 0.5 to 0.6 are the most suitable for the growth and development of woody regenerated trees and shrubs (chapter 3.1.4).

(8) There are three groups of “associated species”[7] found in natural forest. The first group appears most frequently, and includes three species (*Machilus odoratissima*, *Liquidambar formosana*, and *Canarium album*). The second group normally appears, and includes eight species (*Erythrophleum fordii*, *Cinnamomum obtusifolium*, *Cleistocalyx circumcissa*, *Trema orientalis*, *Wrightia annamensis*, *Schefflera octophylla*, and *Symplocos laurina*). The two species in the third group (*Anthocephalus indicus* and *Michelia mediocris*) are rarely found.

(9) Plantation canopy closure of 0.4 to 0.6 is the most suitable for the growth and development of indigenous tree species in the first three years after planting. Four

[7] “Associated species“: trees living in the same time and place that can support each other in their growth and development

of nine species found in local species trials (*Erythrophleum fordii, Michelia mediocris, Machilus odoratissima* and *Canarium album*) have a high survival and growth rate and are suitable to the site conditions (chapter 3.3.1).

The results of this research confirm that site conditions and the micro-climate under the plantation canopies ten years after establishment are changing significantly in the positive way. The silvicultural treatments can be applied to transform pure plantation into mixed plantation based on some major criteria as follows:

(a) The selection of site conditions:

- Foothill and hillsite locations with soil depth layer > 40 cm, where ground vegetations especially *Eupatorium odoratum, Euphorbia thymifoblia,* and Fern species are at good growth.
- Mixed *Acacia auriculifomis* and *Pinus massoniana* plantation with canopy closure range 0.5 – 0.7.

(b) The selection of indigenous species:

- Natural regenetation under a plantation canopy with height of more than 1.5 m and a relative abundance of > 5 %.
- A survival rate more than 85 %, Mean Annual Increment (*MAI*) > 0.9 cm in diameter and > 0.8 m in height three years after planting in the local species trial. Four selected indigenous species: *Canarium album, Erythrophleum fordii, Cinnamomum obtusifolium,* and *Michelia mediocris* for planting.

(c) Silvicultural measures:

- Using the strip planting method with one removing tree line and two residual tree lines with a canopy closure of forest plantation ≈ 0.3 - 0.4 (see fig. 24 in Chapter 3.3.1).
- Planting density of 555 tree/ha (spacing of 9 m x 2 m)
- Using four mixed planting methods as following:

  Canarium album + Erythrophleum fordii + Michelia mediocris = 3+2+1
  Canarium album + Erythrophleum fordii + Cinnamomum obtusifolium = 3+2+1
  Canarium album + Cinnamomum obtusifolium + Erythrophleum fordii = 3+2+1
  Canarium album + Michelia mediocris + Erythrophleum fordii =3+2+1

6 References

Alder, D. and T. J. Synnott (1992). "Permanent Sample Plot Techniques for Mixed Tropical Forest." Tropical forestry papers No.25. Oxford Forestry Institute, Department of Plant Sciences, University of Oxford. Oxford University Press

Anonymous (1999). "The Multi - Storied Forest Management in Malaysia, 1999.".

Anonymous (2006). "The socio-economic situations in 2006 of Lucngan District, Bac Giang Province, Vietnam." Unpublished report.

Anonymous (2007). "The socio-economic situations in 2007 of Luc Ngan District, Bac Giang Province, Vietnam." Unpublished report.

Anonymous (2010). "Increase of forest fires in 2010." http://www.xaluan.com/modules.php?name=News&file=article&sid=234843.

Anonymous (2011). "Summary of hydro-meteorological monitoring (2000 - 2010) of Luc Ngan Hydro-Meteorological Station, Bac Giang Province, Vietnam." Unpublished report.

Anonymous. (2011a). "The result of Five Millions Hectare Reforestation Programme (5MHRP)." http://suckhoedoisong.vn/20111031091824360p0c61/ky-hop-thu-2-quoc-hoi-khoa-xiii-du-an-trong-moi-5-trieu-ha-rung-chua-phat-huy-het-hieu-qua.htm.

Anonymous. (2011b). "Forest fire in Kon Tum Province, Vietnam in 2011 http://bhxhkontum.gov.vn/index.php?option=com_content&view=article&id=89:chayrung&catid=39:tin-trong-tnh&Itemid=45."

Anonymous, F. p. (1999). "The Multi - Storied Forest Management in Malaysia, 1999.".

Apel, U. (2000). "The final review and assessment of afforestation sites in Lang Son and Bac Giang Province, Vietnam(KfW Project 1) " Unpublished report.

Avis, T. J., V. Gravel, H. Antoun and R. J. Tweddell (2008). "Multifaceted beneficial effects of rhizosphere microorganisms on plant health and productivity." Soil Biology & Biochemistry 40(7): 1733-1740.

Balloi, A., E. Rolli, R. Marasco, F. Mapelli, I. Tamagnini, F. Cappitelli, S. Borin and D. Daffonchio (2010). "The role of microorganisms in bioremediation and phytoremediation of polluted and stressed soils." Agrochimica 54(6): 353-369.

Bang, D., C. Liem and D. Thu (1975). "Script of pedology practise. Hanoi."

Bao, V. (2005). "Vietnam forest cover reaching 36.7%." http://vietbao.vn/Khoa-hoc/VN-Do-che-phu-rung-dat-36-7/40102645/188/.

Beckman (1934) "pH meter. http://www.karl-belser.com/History/BeckmanArnold.pdf;"

Benjamín, J.(2009) "Growth, survival, density, biomass partitioning and morphological adaptations of natural regeneration in Fagus sylvatica." Dendrobiology 61(3-11):11.

Binh, N. N., L. D. Kha, N. X. Lieu, N. H. Nghia, H. H. Thinh, H. S. Dong, N. H. Quan and V. V. Me (2004a). Species selection for the afforestation Programme in Viet Nam (Forestry Handbook, MARD), Transportation Publishing House, Ha Noi, Viet Nam.

Binh, N. N., P. D. Tuan, L. T. Thua, N. H. Quan, U. Apel, N. H. Vinh, H. Chuong, n. T. Thanh and D. Phong (2004b). Afforestation (Forestry Handbook, MARD). Ha Noi, Vietnam, Transportation Publishing House.

Biodiversity, F. (2012). "Convention on Biological Diversity http://www.cbd.int/forest/ definitions.shtml."

Brack, C. (1999). "Stand height curve; Forest Measurement and Modelling. http:// fennerschool-associated.anu.edu.au/mensuration/hgtcurve.htm."

Brower, J. E. and J. H. Zar (1984). Field and Laboratory Methods for General Ecology, McGraw-Hill Higher Education.

Carnevale, N. J. and F. Montagnini (2002). "Facilitating regeneration of secondary forests with the use of mixed and pure plantations of indigenous tree species." Forest Ecology and Management 163(1-3): 217-227.

Carter, W. K. and T. S. Fredericksen (2007). "Tree seedling and sapling density and deer browsing incidence on recently logged and mature non-industrial private forestlands in Virginia, USA." Forest Ecology and Management 242(2-3): 671-677.

Chandrapal, S. B. and L. S. Lodhiyal (2010). "Ecological trends of under canopy species of eucalyptus plantation in Bahabhar and Tarai region of Indian centeral Himalaya." International Scientific Reseach Journal; 2(2,2010): 118-127.

Chat, N. B. (1995a). "Mixed plantation in Vietnam." Science and Technology Journal of Agriculture & Rural development 7: 95.

Chien, N. D. (2009). "Insect outbreak in *Pinus massoniana* plantations in Lang Son Province, Vietnam." http://www.baomoi.com/Home/SucKhoe/www.tienphong.vn/Dich-sau-rom-thong-bung-phat/3301814.epi.

Chinh, N. N., C. T. Chung, V. V. Can., N. X. Dung., V. V. Dung., N. K. Dao., T. Hop., T. T. Oanh., N. B. Quynh. and N. N. Thin. (1996). Vietnam Forest Trees. Hanoi, Vietnam, Agricultural Publishing House.

Co, L. P. (1995). "Selection of indigenous species for the forest rehabilitation programme in Song Da River, Pung Luong, Mu Cang Chai, Vietnam." Journal of Forestry (Vietnam) 10: 22- 23.

Cruz, D., L. U. Luna and A.C (1994). "Effects of Acacia auriculiformis and Gmelina arborea on soil and microclimate of degraded grassland in Nueva Ecija, Philippines. ." Japan International Research Center for Agricultural Sciences (JIRCAS), Tsukuba, Japan,(The International Symposium on Rehabilitation of Degraded Forest Lands in the Tropics): 46-54.

Curtis, J. T. and R. P. McIntosh (1951). "An upland forest continuum in the Prairie-Forest border region of Wisconsin." Ecology 32(3): 476-496.

Cusack, D. and F. Montagnini (2004). "The role of native species plantations in recovery of understory woody diversity in degraded pasturelands of Costa Rica." Forest Ecology and Management 188(1-3): 1-15.

David, G. C., J. L. Stone and A. Rosas (2008) "A comparison of the phytosociology and dynamics of three foodplain (Várzea) forests of known ages, Rio Juruá, western Brazilian Amazon."

Do, T. V. and N. B. Van. (2009). "Natural regeneration of indigenous tree species under plantation canopies and bare lands in Nam Lau Commune, Son La Province, Vietnam http://www.fsiv.org.vn/index.php?module=detail&object=article&catID=169&artID=931."

Duc, T. M. (2006). "Technical guideline for production of indigenous species for the forest rehabilitation programme in the Centre of Vietnam." Unpublished report.

Dung, N. A., D. T. Duong and N. V. Nghia (2008). The report of establishment the local species trial in Luc Ngan, Bac Giang (Unpublished report). Ha Noi, Forest Science Institute of Vietnam.

Dung, T. (2011). "Pinus plantations were destroyed by insect in Nghe An Province, Vietnam." http://m.24h.com.vn/tin-tuc-trong-ngay/nghe-an-sau-rom-tan-cong-ca-nguoi-lan-cay-c46a384753.html.

Duong, N. Q. (2009). "The natural regeneration of Acacia mangium Wild in the North-East Viet Nam. Unpublished report."

FAO (1988). Soil map of the world. Rome, Revised Legend.

FAO. (2000). "Statistical Databases. Roundwood, Sawnwood, Wood-based panels. http://apps.fao.org). ."

FAO. (2001). "State of the World's Forest. Words and Publications Oxford 2001. ftp://ftp.fao.org/docrep/fao/003/y0900e/y0900e00.pdf."

FAO (2010). "Global Forest Resources Assessment 2010 (Main report)." FAO Forestry paper 163: 333.

Felfili, J. M. (1997). "Diameter and height distributions in a gallery forest tree community and some of its main species in central Brazil over a six-year period (1985-1991)." Revta brasil. Bot., São Paulo 20(2): 155-162.

Feroz, S. M., A. Hagihara and M. Yokota (2006). "Stand structure and woody species diversity in relation to stand stratification in a subtropical evergreen broadleaf forest " Journal of Plant Research 119(4): 293-301.

FIPI (1997). "Forest cover in Vietnam (phase II). Forest Inventory and Planning Institute, Hanoi, Vietnam." Unpublished report.

FIPI, F. I. a. P. I. (1996). "Vietnam Forest Trees." Agricultural Publishing House, Hanoi, Vietnam.

Fisher, R. F. (1995). "Amelioration of degraded rain forest soils by plantations of native trees." Soil Science Society of America Journal 59(2): 544 - 549.

FRA (2000). "Definetions Related to Planted Forests - PRA WP 79." www.fao.org /docrep/007/ae373e/AE374E02.htm.

Francis, M. (2006). "Dictionary of Forestry." Biotech Books, Delhi - 110035: 312.

FSIV (2000). Using of indigenous species for the afforestation programme in Vietnam (Forest Science Institute of Vietnam- Japan International Cooperation Agency; JICA). Ha Noi, Vietnam, Agricultural Publishing House.

FSIV (2005). "The relationship between tree species in natural forest in Vietnam. http://fsiv.org.vn/?module=detail&object=article&catID=9&artID=44#."

Gates, D. M. and D. Murray (1980). "Biophysical Ecology." Springer-Verlag; New York, USA: 611.

Gee, G. and J. Bauder, Eds. (1986). Particle-size analysis. p. 383-411. In A. Klute (ed.) Methods of soil analysis. Part 1. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Grubb, P. J. (1995). "Mineral nutrients and soil fertility in tropical rainforest. In: Lugo, A.E., Lowe,C. (Eds), ." Tropical Management and Ecology. Springer, New York: pp 308 - 330.

Guariguata, M., Rheingan, R., Montagnini, F. (1995). "Early woody invation under tree plantations in Costa Rica: Implication for forest restoration. Restor." Forest Ecology and Management 3: 252-260.

Hagihara, A., S. M. Feroz and M. Yokota (2008). "Canopy Multilayering and Woody Species Diversity of Subtropical Evergreen Broadleaf Forest, Okinawa Island." Pacific Science 62(3): 363-367.

Hale, S. E. (2004). "Managing Light to Enable Natural Regeneration in British Conifer Forests." Imformation Note by Sophie Hale Forest Research, Forestry Commission, Edinburgh: 6.

Hamilton, A. J. (2005)."Species diversity or biodiversity?" Environmental Management(75): 89–92.

Hien, T. (2004). "The growth and development of indigenous tree species in trial model under Pinus massoniana plantation canopy at Dai Lai - Vinh Phuc Province, Vietnam. Unpublished report.".

Hoan, P. X. (2002). "Forest rehabilitation by indigenous species in Vietnam." Science and technology Journal of Agriculture & rural development (Vietnam) 10: 935-936.

Hoang, H. D. T. (2005). Restoration of degraded natural forest in the North Central Coast region of Vietnam. Freiburg University, Germany.

Hoorman, J. J. (2011). "The Role of Soil Bacteria." Agriculture and Natural Resources; The Ohio State University: 13-11.

Hoorman, J. J. and R. Islam (2010). "Understanding Soil Microbes and Nutrient Recycling." Agriculture and Natural Resources; , The Ohio State University: 16-10.

Hung, P. Q. (2008). Structure and Light Factor in Differently Logged Moist Forests in Huong Son-Vu Quang, Vietnam. Göttingen University, Germany.

Hung, T. V. (1993). Biological characteristic of some indigenous tree species for enrichment planting programme in Vietnam (Canarium album, Peltophorum pterocarpum). Hanoi, Vietnam, Agricultural Publishing House.

Husch, B., T. W. Beers and J. A. Kershaw (2003). "Forest mensuration." Wiley, Hoboken xii: 443pp.

Huyen, P. T. (1997). "Characteristics of Maglietia fordiana hemsl Oliv at Ba Vi National Park, Vietnam." Unpublished report.

IUCN, UNDP and WWF (1993). The save our earth. Ha Noi, Vietnam, Scientific and Technical Publishing House

Jordan, C. F. and E. G. Farnworth (1982). "Natural vs. plantation forest: A case study of land reclamation strategies for the humic tropics." Environmental Management 6: 485-492.

Kelty, M. J. (2006). "The role of species mixtures in plantation forestry." Forest Ecology and Management 233(2-3): 195-204.

Khan, S. A. (2004). "Methodology for Assessing Biodiversity, Centre of Advanced Study in Marine Biology Annamalai University - India."

Khanh, V. H. (2003). "Growth rate of indigenous tree species in the reserved forests in Doan Hung District, Phu Tho Province." Unpublished report.

Kjeldahl, J. (1883). "A new method for the estimation of nitrogen in organic compounds." Z. Anal. Chem 22: 366.

Kleinn, C., N. Bhandari, L. Fehrmann, T. Y. Lam, H. Yang and S. Schnell (2009). "Forest Inventory." Faculty of Forest Sciences and Forest Ecology, Georg-August-Universität Göttingen, Germany.

Koch, R. (1876). "http://www. nobelprize.org/nobel_prizes/medicine/laureates/1905/ koch-bio.html;http://www.answersingenesis.org/articles/aid/v5/n1/koch-reation-and-specificity-of-germs."

Kuusipalo, J., G. Adjers, Y. Jafarsidik, A. Otsamo, K. Tuomela and R. Vuokko (1995). "Restoration of natural vegetation in degraded *Imperata cylindrica* grassland: understorey development in forest plantations." Journal of Vegetation Science 6(2): 205 - 210.

Kyaw, N. N. (2003). Site Influence on Growth and Phenotype of Teak (*Tectona grandis* Linn.f.) in Natural Forest of Myanmar. Göttingen, Cuvillier Verlag Göttingen.

Lamb, D. (2011). "Regreening the Bare Hills, Tropical Forest Restoration in the Asia - Pacific Region." World Forest VIII: 141, 234, 235, 270 and 271; Springer.

Lamprecht, H. (1989). "Silviculture in Troppics: Tropical Forest Ecosystems and Their Tree Species - Possibilities and Methods for Their Long-Term Utilization." Eschborn.

Lan, P. N. (1991). "Mixed plantation." Journal of Vietnam Forestry 3: 9.

Lan, P. N. (1994). "The ecological charateristic of Erythrophloeum fordii Oliv." Forestry University of Xuan Mai, Ha Tay, Vietnam.

Lee, E. W. S., B. C. H. Hau and R. T. Corlett (2005). "Natural regeneration in exotic tree plantations in Hong Kong, China." Forest Ecology and Management 212(1-3): 358-366.

Lee, Y. K., D. K. Lee, S. Y. Woo, P. S. Park, Y. H. Jang and E. R. G. Abraham (2006). "Effect of Acacia plantations on net photosynthesis, tree species composition, soil enzyme activities, and microclimate on Mt.Makiling." Photosynthetica 44(2): 299 - 308.

Leibundgut, H. (1956). "Beipiel einer Bestandesanalyse nach neuen " Baumklassen. IURO, Oxford.

Loetsch, F., F. Zöhrer and K. E. Haller (1973). Forest inventory. v.2. München, Verlagsgesellschaft.

Lucngan (1997). "Site conditions in Commune of Dong Coc, Tan Hoa and Phu Nhuan, Luc Ngan District, Bac Giang Province, Vietnam (KfW1 Project)." Unpublished report.

Lugo, A. E. (1992). "Comparision of tropical tree plantations with secondary forest of similar age." Ecological Monographs 62(1): 41; http://www.jstor.org/stable/2937169?seq=1.

Lugo, A. E., J. A. Parrotta and S. Brown (1993). "Loss in species caused by tropical deforestation and their recovery through management." Ambio 22(2-3): 106-109.

Magurran, A. E. (1988). Ecological diversity and its measurement). New Jersey, Britain, Princeton University Press.

MARD (1984). Decision No. 682 B/QĐKT dated August 1st 1984 refer classification of natural forest. Forest Ministry of Vietnam, Unpublished report.

MARD (1995a). "The feasiblity study document of the afforestation Project in Bac Giang and Lang Son Provinces, Vietnam (KfW1 Project)." Unpublished report.

MARD (1996). Dictionary of Forestry. Hanoi, Vietnam, Agricultural Publishing House.

MARD (1996a). Guideline on site mapping classification for the KfW1 Project in Lang Son and Bac Giang Provinces, Unpublished report.

MARD (1996b). "Technical guideline to establishment of forest plantation stands in Lang Son and Bac Giang Project, Vietnam (KfW1)." Unpublished report.

MARD (2002). "Guideline to enrichment planting for the KfW3 Project in Lang Son, Bac Giang and Quang Ninh Provinces, Vietnam." Unpublished report.

MARD (2004). Vietnam Forestry Hanbook for establishing plantation forests, GTZ - REFAS Project. Hanoi, Vietnam, The transportation Publishing House.

MARD (2011). "Decision No. 1828/QĐ-BNN-TCLN Dated to the August 11th, 2011 on the an announcement of status of Vietnam´s forest in 2010." Unpublished report.

Mette, N. N., A. Winding, S. Binnerup, B. M. Hansen, N. B. Hendriksen and N. Kroer (2002). "Microorganisms as indicators of soil health." NERI Technical Report No. 388 - 2002; Ministry of the Environment, National Environmental Research Institute ; Denmark.

Michelsen, A., Lisanework Nigatu, I.Friis& N.Holst (1996). "Comparision of understory vegetation and soil fertility in plantations and adjacent natural forests in the Ethiopian highlands." Journal of Applied Ecology 33: 627-642.

Montagnini, F., D. Cusack, B. Petit and M. Kanninen (2005). "Environmental Services of Native Tree Plantations and Agroforestry Systems in Central America." Environmental Services of Agroforestry Systems 21(1): 51-67.

Montagnini, F., Guariguata,M., Ribeiro,N.,Mariscal,A., (1999). "Regeneration natural in plantation pure and mixed the especies native." Turrialba, Costa Rica: 324-327.

Montagnini, F. and C. F. Jordan (2005). Tropical Forest Ecology. The basic for conservation and Management. Springer, Berlin and Heidelberg.

Montagnini, F. and C. Porras (1998). "Evaluating the role of plantations as carbon sinks: An example of an integrative approach from the humid tropics." Environmental Management 22(3): 459-470.

Nghia, N. H. (1997). "Paradoxes of indigenous species." Journal of Vietnam Forestry 8: 3-5.

Ohta, S. (1990). "Initial soil changes associated with afforestation with Acacia auriculiformis and Pinus kesiya on denuded grasslands of the Pantabangan area, Central Luzon, the Philippines." Soil Science and Plant Nutrition 36(4): 1629 - 1642.

Oliver, C. D. and B. C. Larson, Eds. (1990). Forest Stand Dynanics. New York, McGraw-Hill Inc.

Oliver, C. D. and B. C. Larson, Eds. (1996). Forest Stand Dynamics, Copyright 1996 by John Wiley & Sons,Inc.

Pancel, L. (1993). Tropical Forestry Handbook. Hamburg Germany, springer - Verlag.

Parrotta, J. A. (1992). "The role of plantation forest in rehabilitating degraded tropical ecosystems." Agriculture Ecosystems & Environment 41(2): 115 - 133.

Parrotta, J. A. (1995). "Influence of overstory composition on understory colonization by natives species in plantation on degraded tropical site." Journal of Vegetation Science 6(5): 627-636.

Parrotta, J. A., J. W. Turnbull and N. Jones (1997). "Catalyzing native forest regeneration on degraded tropical lands." Forest Ecology and Management 99(1-2): 1 - 7.

Picard, N., S. Magnussen, L. N. Banak, S. Namkosserena and Y. Yalibanda (2010). "Permanent sample plots for natural tropical forests: A rationale with special emphasis on Central Africa." Environmental Monitoring and Assessment 164(1-4): 279-295.

Piotto, D., D. Craven, F. Montagnini and F. Alice (2009). "Silvicultural and economic aspects of pure and mixed native tree species plantations on degraded pasturelands in humid Costa Rica." New Forests 39(3): 369-385.

Piotto, D., E. Viquez, F. Montagnini and M. Kanninen (2004). "Pure and mixed forest plantations with native species of the dry tropics of Costa Rica: comparison of growth and productivity." Forest Ecology and Management 190(2-3): 359-372.

Powers, J. S., J. P. Haggar and R. F. Fisher (1997). "The effect of overstory composition on understory woody regeneration and species richness in 7-year-old plantations in Costa Rica." Forest Ecology and Management 99(1-2): 43-54.

Raich, J. W. and A. Tufekciogul (2000). "Vegetation and soil respiration: Correlations and controls." Biogeochemistry 48(1): 71-90.

Richards, P. W. (1952). The tropical rain forest. Cambridge, Cambridge University Press.

Richards, P. W., Ed. (1996). The tropical rain forest, second editions, Cambridge University Press.

Riikka, O. (1998). "Removal of Acacia magium overstory increased growth of underplanted Anisotera marginata (Dipterocarpaceae) on an Imperata cylindrical grassland site in South Kalimantan, Indonesia." New Forest 17: 71-80, 1998. Kluwer Academic Publisher. Printed in the Netherlands.

Robert, G. W. and S. J. Colombo (2001). "Regenerating the Canadian Forest; Ontario Ministry of Natural Resources." Fitzhenry & Whiteside; Markham, Ont.: 650.

Rubin, B. D., P. D. Manion and D. Faber-Langendoen (2006). "Diameter distributions and structural sustainability in forests." Forest Ecology and Management 222(1-3): 427-438.

Senbeta, F. and D. Teketay (2001). "Regeneration of indigenous woody species under the canopies of tree plantations in Central Ethiopia." Tropical Ecology 42(2): 175-185.

Silva, R. P., J. dos Santos, E. S. Tribuzy, J. Q. Chambers, S. Nakamura and N. Higuchi (2002). "Diameter increment and growth patterns for individual tree growing in Central Amazon, Brazil." Forest Ecology and Management 166(1-3): 295-301.

Spurr, S. H. and B. Barnes (1992). "Forest ecology." Krieger Pub.Co., Malabar, Fla. x: 687.

Sucre, E. B., J. W. Tuttle and T. R. Fox (2011). "The Use of Ground-Penetrating Radar to Accurately Estimate Soil Depth in Rocky Forest Soils." Forest Science 57(1): 59-66.

Thang, H. V. (2003). "Natural regeneration of broad-leaved species under the *Dendrocalamus membranceus Munro* plantation canopies in Ngoc Lac, Thanh Hoa and Cau Hai, Phu Tho Province, Vietnam." Unpublished report.

Thao, H. (2011). "The forest resource in Vietnam." http://thuviensinhhoc.com/chuyen-de-sinh-hoc/sinh-thai-hoc/2318-tai-nguyen-rung-va-nguyen-nhan-suy-thoai-rung-o-viet-nam.html.

Them, N. V. (1992). "The natural regeneration of Dipterocarpus dyeri Pierre species in the moist and semi-evergreen tropical forest in Dong Nai Province, Vietnam." Unpublished report.

Thiep, T. X. (1997). "The selection of indigenous tree species for 327 forest rehabilitation Programme." Science and technology Journal of Agriculture & rural development 4,5: page 18 - 19.

Tho, H. V. (1998). "The ecological factor under five-year-old *Erythrophleum fordii* Oliver plantation canopy in Luot mountain, Xuan Mai, Ha Noi, Vietnam." Unpublished report.

Thuong, P. N. (2003). "The natural regeneration of indigenous tree species after shifting cultivation in Bacthai Province, Vietnam." Unpublished report.

Tiurin, N. W. K. (1951). "Metodikie analiza dla sprawnitielnogo izu- czenija sostawa poczwiennogo pieregnoja ili gumusa. Rabota po organiczeskomu wieszczestwu poczwy. Moskwa."

Trung, T. V. (1970). Vietnam plants. Hanoi, Vietnam, Scientific and Technique Publishing House.

Trung, T. V. (1998). Tropical forest ecosystems in Viet Nam. Hanoi, Vietnam, Scientific and Technical Publishing House.

Tung, P. T. (2006). "The growth and development of indigenous tree species under Acacia plantation canopies in Hai Van Pass, Vietnam." Unpublished report.

Ulrich, L. (2008). "Physiological Ecology of Tropical Plants, second Edition." Technische Hochschule Darmtadt, Institut Fuet Botanik, Germany Berlin: Springer: 458.

Van Laar, A. and A. Akca, Eds. (1997). Forest mensuration. Göttingen, Cuvillier Verlag.

Viet, T. Q. (2001). The technical guideline for planting Paulownia species. Hanoi, Vietnam, Agricultural Publishing House.

Walker, L. R., D. A. Wardle, R. D. Bardgett and B. D. Clarkson (2010). "The use of chronosequences in studies of ecological succession and soil development." Journal of Ecology 98(4): 725-736.

Watt, A. D. (1992). "Insect pest population dynamics: effects of tree species diversity. In: Cannel, M.G.R., Malcolm,D.C., Robertson, P.A (Eds). The ecology of Mixed - Species Stand of tree." Blackwell Scientific Publication, Oxford: pp. 267 - 275.

WCMC (1994). "The World Conservation Monitoring Centre. <http://www.wcmc. org.uk/infoserv/countryp/vietnam/ chapter3.html>."

Weidelt, H. J. (1999). "Tropisher Waldbau, Forstliche Fakultät, Univesität, Göttingen Germany (unpublished)."

Wenger, K. F., Ed. (1984). Forestry Handbook, second edition. A Wiley - Interscience publication, printed in the USA.

Wolda, H. (1981). "Similarity indices, sample size and diversity." Oecologia 50: 296-302.

Xu, M., J. Q. Chen. and Y. Qui (2002). "Growing-season teperature and soil moisture along a 10 km transect across a forested landcape.- Climate Res." Climate Research Clim Res 22: 57-72.

Xu, M., Y. Qi, J. Q. Chen and B. Song (2004). "Scale-dependent relationships between landscape structure and microclimate." Plant Ecology 173(1): 39-57.

Yanes, C. V. and H. Smith (1982). "Phytochrome control of Seed germination in the Tropical rain Forest pioneer trees *Cecropja Obtusjfolia* and *Pirer auritum* and its ecological significane." New Phytol 92: 477- 485.

Yuning., T. and M.-g. LIU (2007). "Studies on Rules of Natural Regeneration of Chinese Pine and Artificial Promoting Measures in Chaoyang Region." Agricultural science paper of China.

Zhou, G. Y., X. H. Wei and J. H. Yan (2002). "Impacts of eucalyptus (Eucalyptus exserta) plantation on sediment yield in Guangdong Province, Southern China - a kinetic energy approach." Catena 49(3): 231-251.

7 Appendix

Appendix 1: The results of soil analysis in the research areas (analysed in the soil laboratory of the National Institute of Agricultural Planning and Projection, Vietnam [NIAPP])

	pH [H_20]	**pH** [KCL]	**OM** [%]	**Totally of NPK** [%]			**Availability of NPK** [mg/100g]			Soil bulk density [g/cm^3]	Praticle density [g/cm^3]	Microorganisms [n/100g soil]
				N	P_2O_5	K_2O	N	P_2O_5	K_2O			
Types of forest												
Under plantation canopy*	5.9	4.2	2.1	0.14	0.03	1.29	5.6	2.1	8.4	1.20	2.6	6.58×10^7
Bare hills	5.1	4.0	1.5	0.13	0.01	1.94	4.2	1.9	10.8	1.16	2.7	1.67×10^7
Under natural forest canopy	4.8	3.7	2.0	0.13	0.04	0.49	5.9	5.5	2.6	1.13	2.5	5.10×10^7
Positions in forest plantations*												
Foothill	4.7	3.8	2.9	0.17	0.02	1.54	6.8	2.0	9.1	1.17	2.6	7.77×10^7
Hillside	4.9	3.8	1.9	0.13	0.04	1.01	5.4	2.2	8.3	1.20	2.6	6.45×10^7
Hilltop	5.1	3.9	1.6	0.13	0.04	1.51	4.9	1.9	7.8	1.23	2.7	5.92×10^7

(*Ten-year-old *Pinus massoniana* and *Acacia auriculiformis* plantation)

Appendix 2: Indigenous tree species planted in local species trial in 2007 in Luc Ngan - Bac Giang Province

Commune	Village	Block	Areas [ha]	Species
Dong Coc	Thuong B	H_1	1.5	Ca, Ci and E
		H_2	1.5	Ma, Ci and E
		H_3	1.5	Ca, Ci, LD, and LF
		H_4	1.5	Ci, LD, and Mi
		G_1	1.5	Ci, LD, and Ca
		G_2	1.5	Ci, Q, and Ca
		G_3	1.5	Ci, LF, and Ca
		K_1	1.5	Ci, Q, H, Ma and Ca
		K_2	1.5	Ci, Q, LF and Ca
		K_3	1.5	C, LF and Ma
		K_4	1.5	Ci, Q, and Ca
		I_1	1.5	Ci, Ma and LF
		I_2	2.0	Ci, Q, and Ca
	Tu Tham	H_5	2.0	Ci, Ca, and Mi
		C_1	2.0	Ci, Q, and Mi
Tan Hoa	Vat Phu	C_2	2.5	Ci, Q, LD, Ca, E, and H
		D_1	3.0	Ci, Q, Ca, and Mi
Total			**29.5**	

(**Ca:** *Canarium album* ; **Ci:** *Cinnamomum obtusifolium*; **E:** *Erythrophleum fordii*; **Ma**: *Machilus odoratissima;* **LD***: Lithocarpus ducampii;* **LF**: *Lithocarpus fissus* **Mi:** *Michelia mediocris*; **Q:** *Quercus platycalyx* ; **H:** *Hopea odorata*)

Appendix 3: List of species in the research areas in Luc Ngan District, Bac Giang Province, Vietnam

Scientific name	**Local name**	**Family**
Acacia auriculiformis. Cunn	Keo lá tràm	Fabaceae
Acacia confuse Merr.	Đài loan tương tư	Leguminosae
Acacia mangium Wild	Keo tai tượng	Fabaceae
Albizia chinensis (Obs.) Merr	Muồng sống rắn	Mimosoideae
Altingia chinensis (Champ.) Oliver ex Hance	Tô hạp	Hamameliaceae
Alstonia scholaris (L.) R.Br	Sữa (Mò cua)	Apocynaceae
Anisoptera costata Korth	Vên vên	Dipterocarpaceae
Anthocephalus indicus (A.rich)	Gáo lá tròn	Rubiaceae
Aporusa tetrapleura (Hance)	Thẩu tấu lá dầy	Euphorbiaceae
Ardisia crenata (Sims)	Trọng đũa	Primulaceae
Artemisia annual L	Thanh hao	Asteraceae
Burretiodendron hsienmu Ching et Hu	Nghiến	Tiliaceae
Camellia oleifera C.Abel	Sơn trà	Theaceae
Canarium album Raeusch	Trám trắng	Burseraceae
Canarium tramdenum Dai et Jakovl	Trám đen	Burseraceae
Cassia siamea Lamark	Muồng đen	Leguminosae
Castanopsis Boisii Hickel et Camus	Dẻ yên thế	Fabaceae
Castanopsis boisii Hickel et Camus	Giẻ yên thế	Fabaceae
Castanopsis tonkinensis Seem	Cà ổi	Fagaceae
Cedrela odorata .L	Bồ hòn	Meliaceae
Choerospondias axillaris Roxb	Xoan nhừ	Ancardiaceae
Chukrasia tabularis A.Juss	Lát hoa	Meliaceae
Cinnamomum balansae Lee	Vù hương	Lauraceae
Cinnamomum camphora (L.) Presl	Long não	Lauraceae
Cinnamomum inners Reinw	Quế lợn	Lauraceae
Cinnamomum obtusifolium Ness	Re gừng	Lauraceae
Cinnamomun cassia Bl	Quế	Lauraceae
Cleistocalyx circumcissa (Gagn)	Trâm vối	Myrtaceae
Crateva nurvala L	Bún sừng	Capparidaceae
Cratoxylon maingayi D.Hook	Thành ngạnh	Clusiaceae
Cunninghamia lanceolata (Lamb.) Hook	Sa mộc	Taxodiaceae
Cupressus lusitanica Mill.	Tùng mốc	Cupressaceae
Dendrocalamus membranceus Munro	Cây luồng	Bambusaceae
Desmodium gangeticum (L.)	Thóc lép	Fabaceae
Dicranopteris linearis (Burm.f.) Underw.	Ràng ràng	Gleicheniaceae

Appendix 3 (Continued)

Scientific name	**Local name**	**Family**
Diptercarpus dyeri Pierre	Dầu song nàng	Dipterocarpaceae
Dipterocarpus alatus Roxb	Dầu rái	Dipterocarpaceae
Dipterocarpus retusus Bi	Chò nâu	Dipterocarpaceae
Dracontomelon duperreanum Pierre	Sấu	Anacardiaceae
Endospermum chinense Benth	Vạng trứng	Euphorbiaceae
Engelhardia chrysolepis Hance	Chẹo tía	Juglandaceae
Erythroloeum fordii Oliver	Lim xanh	Caesalpiniaceae
Eucalyptus camaldulensis Dehnhardt	Bạch đàn trắng	Myrtaceae
Eucalytus globules Labill	Khuynh diệp cầu	Myrtaceae
Eupatorium odoratum	Cây cộng sản	Asteraceae
Euphorbia thymifoblia	Cỏ sữa	Euphorbiaceae
Fernandoa brilletii (P.Dop) Steenis	Đinh thối	Bignoniaceae
Fokiania hodginsii Henry and Thomas	Pơ mu	Cupressaceae
Garcinia cowa Warb	Máu chó lá to	Myristicaceae
Garcinia cowa Roxb	Tai chua	Clusiaceae
Gmelina arborea Roxb.	Lõi thọ	Lamiaceae
Grewia paniculata Roxb	Mé cò ke	Tiliaceae
Hopea odorata Roxb	Sao đen	Dipterocarpaceae
Liquidambar formosana Hance	Sau sau	Hamamelidaceae
Lithocarpus ducampii (Hick et A.Camus)	Dẻ đỏ	Fagaceae
Lithocarpus ducampii (Hickel et A.Camus)	Dẻ đỏ	Fagaceae
Lithocarpus fissus (Champ.. ex Benth.) A. Camus	Sồi phảng	Fagaceae
Litsea acutivena Hay	Bời lời gân nhọn	Lauraceae
Litsea cubeba (Lour.) Pers.	Màng tang	Lauraceae
Litsea glutinosa Lour	Bời lời nhớt	Lauraceae
Lovoa trichilioides Harms	Óc chó	Meliacea
Machilus odoratissima Ness	Rè vàng (kháo)	Lauraceae
Madhuca pasquieri H.J.Lam	Sến mật	Sapotaceae
Manglietia conifera Dandy	Vàng tâm	Mangnoliacea
Melaleuca quinquenervia (Cav.) S.T.Blake	Tràm	Myrtaceae
Melanorrhoea laccifera Pierre	Sơn huyết	Anacardiaceae
Melastoma candidum D.Don	Mua	Melastomataceae
Melia azedarach Linn	Xoan ta	Meliaceae
Michelia mediocris Dandy	Giổi xanh	Magnoliaceae
Miliusa balansae (Finet et Gagn)	Na hồng	Annonaceae
Morinda parvifolia (Bartl.)	Nhàu lá nhỏ	Rubiaceae

Appendix 3 (Continued)

Scientific name	**Local name**	**Family**
Ormosia balansa Drake	Ràng ràng mít	Leguminosae
Ormosia pinnata (Lour.) Merr	Ràng ràng xanh	Leguminosae
Parashorea chinensis Wang Hsie	Chò chỉ	Dipterocarpaceae
Peltophorum pterocarpum (DC.) K. Heyne	Lim xẹt	Fabaceae
Persea velutina (Champ. ex Benth.) Kosterm.	Kháo lông	Lauraceae
Phoebe cuneata Bi	Kháo	Lauraceae
Phyllanthus emblica L	Me rừng	Phyllanthaceae
Pinus massoniana Lamb	Thông mã vĩ	Pinaceae
Pinus merkusii Jungg.et De Vriese	Thông nhựa	Pinaceae
Pinus patula Schide&Deppe	Thông rủ	Pinaceae
Podocarpus fleuryi Hickel	Kim giao	Podocarpaceae
Podocarpus nerifolius D.Don	Thông tre	Podocarpaceae
Pycnanthus angolensis (Welw.) Warb.	Đậu khấu	Myristicaceae
Pygeum arboreum Endl et Kurz	Xoan đào	Rosacea
Quercus platycalyx Hickel & A.Camus	Dẻ cau	Fagaceae
Rhamnoneuron balansae Gilf	Dó bầu	Thymelaeaceae
Rhodomyrtus tomentosa Ait	Sim	Melastomataceae
Schefflera octophylla (Lour)	Chân chim	Araliacea
Schima wallichii Choisy	Vối thuốc	Theaceae
Shorea roxburrghii G.Don	Sến	Dipterocarpaceae
Symplocos laurina (Wall)	Dung giấy	Symplocaceae
Syzygium wightianum (Wall)	Trâm trắng	Myrtaceae
Tarrietia javannica Bi	Huỷnh	Sterculiaceae
Tectona grandis L.f.	Tếch	Verbenaceae
Terminalia chebula Retz	Chiêu liêu	Combretaceae
Terminalia superba (Engl. & Diels)	Chiêu liêu	Combretaceae
Torricellia angulata	Hu đay	Torricelliaceae
Toona sinensis (A.Juss.) Roem	Tông dù	Meliaceae
Trema orientalis (L.)BI	Hu đay	Ulmaceae
Vatica tonkinensis A.Chev	Táu mật	Dipterocarpaceae
Vernicia fordii Hemsl	Trẩu lùn	Euphorbiaceae
Wendlandia paniculata (Roxb.) DC	Hoắc quang	Rubiaceae
Wrightia annamensis (Dub)	Thừng mực	Apocynaceae

Appendix 4: Result of survey of six trees by point-to-tree distance method in the natural forest in Xa Ly commune, Luc Ngan District, Bac Giang Province, Vietnam.

$IIIA_1$ category		**$IIIa_2$ category**		**$IIIa_3$ category**	
Sample plot	Species	SP	Species	SP	Species
1	*Liquidambar formosana*	**1**	*Liquidambar formosana*	**1**	*Machilus odoratissima*
	Toona sureni		*Machilus odoratissima*		*Cinnamomum obtusifolium*
	Machilus odoratissima		*Canarium album*		*Schefflera octophylla*
	Liquidambar formosana		*Canarium album*		*Litsea cubeba*
	Trema orientalis		*Trema orientalis*		*Erythrophloeum fordii*
	Erythrophloeum fordii		*Cleistocalyx circumcissa*		*Elaeocarpus angustifolius*
2	*Schefflera octophylla*	**2**	*Machilus odoratissima*	**2**	*Albizzia chinensis*
	Cinnamomum obtusifolium		*Cleistocalyx circumcissa*		*Quercus platycalyx*
	Liquidambar formosana		*Liquidambar formosana*		*Cinnamomum obtusifolium*
	Machilus odoratissima		*Erythrophloeum fordii*		*Engelhardta chrysolepis*
	Trema orientalis		*illigera rhodantha*		*Anthocephalus indicus*
	Machilus odoratissima		*Albizzia chinensis*		*Elaeocarpus angustifolius*
3	*Symplocos laurina*	**3**	*Symplocos laurina*	**3**	*Engelhardta chrysolepis*
	Canarium album		*Cinnamomum obtusifolium*		*Canarium album*
	Machilus odoratissima		*Wrightia annamensis*		*Wrightia annamensis*
	Liquidambar formosana		*Machilus odoratissima*		*Liquidambar formosana*
	Michelia mediocris		*Machilus odoratissima*		*Machilus odoratissima*
	Schefflera octophylla		*Cleistocalyx circumcissa*		*Liquidambar formosana*
4	*Cleistocalyx circumcissa*	**4**	*Liquidambar formosana*	**4**	*Machilus odoratissima*
	Erythrophloeum fordii		*Canarium album*		*Liquidambar formosana*
	Machilus odoratissima		*Michelia mediocris*		*Canarium album*
	illigera rhodantha		*Liquidambar formosana*		*Ormosia pinnata*
	Trema orientalis		*Albizzia chinensis*		*illigera rhodantha*
	Canarium album		*Machilus odoratissima*		*Machilus odoratissima*

Appendix 4 (Continued)

IIIA$_1$ category		IIIa$_2$ category		IIIa$_3$ category	
Sample plot	Species	SP	Species	SP	Species
5	*Cleistocalyx circumcissa*	**5**	*Cinnamomum obtusifolium*	**5**	*Cleistocalyx circumcissa*
	Albizzia chinensis		*Machilus odoratissima*		*Peltophorum pterocarpum*
	Machilus odoratissima		*Engelhardta chrysolepis*		*Wrightia annamensis*
	Trema orientalis		*Schefflera octophylla*		*Erythrophloeum fordii*
	Machilus odoratissima		*Michelia mediocris*		*Liquidambar formosana*
	Symplocos laurina		*Symplocos laurina*		*Symplocos laurina*
6	*Schefflera octophylla*	**6**	*Albizzia chinensis*	**6**	*Alstonia scholaris*
	Machilus odoratissima		*Machilus odoratissima*		*Canarium album*
	Erythrophloeum fordii		*Machilus odoratissima*		*Canarium album*
	Liquidambar formosana		*Erythrophloeum fordii*		*Machilus odoratissima*
	Canarium album		*Elaeocarpus angustifolius*		*Elaeocarpus angustifolius*
	Wrightia annamensis		*Ormosia pinnata*		*Cinnamomum obtusifolium*
7	*Cleistocalyx circumcissa*	**7**	*Alstonia scholaris*	**7**	*Canarium album*
	Canarium album		*Gluta compacta*		*Anthocephalus indicus*
	Machilus odoratissima		*Cinnamomum obtusifolium*		*Machilus odoratissima*
	illigera rhodantha		*Machilus odoratissima*		*Michelia mediocris*
	Wrightia annamensis		*Quercus asymmetricus*		*Anthocephalus indicus*
	Albizzia chinensis		*Wrightia annamensis*		*Symplocos laurina*
8	*Quercus platycalyx*	**8**	*Machilus odoratissima*	**8**	*Canarium album*
	illigera rhodantha		*Cinnamomum obtusifolium*		*Machilus odoratissima*
	Liquidambar formosana		*Liquidambar formosana*		*Liquidambar formosana*
	Liquidambar formosana		*Canarium album*		*Symplocos laurina*
	Trema orientalis		*Anthocephalus indicus*		*Erythrophloeum fordii*
	Machilus odoratissima		*illigera rhodantha*		*Cleistocalyx circumcissa*

Appendix 5: Some photos of indigenous tree species planted under mixed *Pinus massoniana* and *Acacia auriculiformis* plantation canopies in Luc Ngan District, Bac Giang Province, Vietnam

Five-month-old *Erythrophleum fordii*

Five-month-old *Michelia mediocris*

Five-month-old *Cinnamomum obtusifolium*

Five-month-old *Canarium album*

Two-year-old *Erythrophleum fordii*

Two-year-old *Cinnamomum obtusifolium*

Two-year-old *Michelia mediocris*

Two-year-old *Machilus odoratissima*

Ten-year-old *Canarium album* plantation in Son Dong District, Bacgiang Province

Ten-year-old *Canarium album* and *Acacia auriculiformis* plantation in Son Dong District, Bacgiang Province

Nine-year-old *Schima Wallichi* and *Acacia Auriculiformis* plantation in Luc Ngan District, Bacgiang Province

Nine-year-old *Castanopsis tonkinensis* and *Acacia Auriculiformis* plantation in Luc Ngan District, Bacgiang Province

Appendix 6: The biological characteristics of eight indigenous species have been planted in the local species trials

QUERCUS PLATICALYX Hickel et A.Camus
VERNACULAR NAME: Dẻ cau
FAMILY: FAGACEAE

Morphology

A medium – sized tree, 18 – 22 m in height. Trunk cylindrical, straight, regularly oblong, Bark greyis Male inflorescence is a catkin spike, tender, flowers small, naked, sparsely arranged. Female flower solitary at axil of leaf, pedicel very short, bract thick at the base. h. Bole 6 – 7m high. Branches long, slender, erect, slightly pendulous at tip. Leaves simple, alternate, concentrated at the end of branches, oblong, glabrous, acutely serrate at ½ of upper part. Apex elongated in to a short point. Base regularly oblong. Veins slender, evident beneath. Petiole nearly 1 cm long, canaliculated on upper side. Stipule small, filiform, caduceus, leaving a scar. Male inflorescence is a catkin spike, tender, flowers small, naked, sparsely arranged. Female flower solitary at axil of leaf, pedicel very short, bract thick at the base. Fruit a slightly concave nut, only enclosing a part of fruit – base, easily caducous when old. Cupule – scales not clear, arranged about 0.6cm high into 8 regular concentric circles with the diameter of 2.8 cm. The margin of cupule slightly serratifide and sparsely tomentose. Fruit obovate, apex acute with many concentric circles 3.5cm in height and 1.7 – 1.9cm in diameter.

Distribution and ecology

Widely distributed in secondary forests of Nghe An, Hoa Binh, Vinh Phu, Ha Tay, Bac Thai, Lang Son, Cao Bang and Quang Ninh from 500m a.s.l downwards. Usually mixed with *Lithocarpus cerebrina, Lithecapus conea, Castanopsis indica* and *Elaeocarpus sp*.

Light – demanding and fast growing tree, strongly regenerated by seeds, usually growing at foot or on gently sloping hills, with clay soil. Flowering in June – August. Fruiting in December – February.

Uses

Timber straight, solid. Used in construction, for household implements and pit-props.

Data sources: Vietnam Forest Trees (FIPI 1996)

LITHOCARPUS DUCAMPII (Hickel et A. Camus) Camus
VERNACULAR NAME: Dẻ đỏ
FAMILY: FAGACEAE

Morphology

A large tree, up to 30m height. Trunk straight and cylindrical, regularly tapered. Bark pink-brown, regularly splitted and soft. Late branched. Twigs slender, white-tomentose when young. Crown dense and large. Leaves regularly arranged on branches, ovate or lanceolate, 10 – 12cm long and 4 – 4.5cm wide, apex acute, gradually narrowing, base narrowing. Leaf-blade thick, coriaceous, glossy, dark green, tomentose beneath. Midrib evident; lateral veins slender, 9-12 pairs. Petiole slender, 1cm long. Inflorescence monosexual, catkin-like. Male inflorescence with thick and glossy pedicel, slightly oblique, terminal. Male flower: perianth 6 segments, caducous. Stamens 10-12; filament long and lanky. Female inflorescence consisting of 2-5 small flowers. Perianth small and lobed. Ovary inferior, trilocular, 2 ovules in each locule. Infructescence 9-10 long. Cupule sessile, formed from hard bracts, arranged in bundleds of 3 fruits, 1-2cm in diameter, bearing many acute ovate scales, thinly scaled and shortly hairy at the base. Fruit conical, 0.6-1cm in diameter.

Distribution and ecology

Mainly distribution in secondary forests (rarely in primary forest) of Tuyen Quang, Bac Thai, Lang Son, Ha Bac and Quang Ninh Province, at altitudes of 100-500masl.. Light – demanding tree with rich developed roots. Prefers clay and sandy – clay soil, and has the capacity to protect and ameliorate the soil. Natural regeneration is strong in secondary forest after selective exploitation with a remaining forest over of 0.3-0.5 Flowering in June- July, fruits mature in September-November.

Uses

Timber valuable, pinkish, hard with fine veins. Used in construction, making of sleepers, shutters and building of boats and ships. A valuable tree, with limited distribution. Studies of suitable measures for protection and development of this species are necessary.

Data sources: Vietnam Forest Trees (FIPI 1996)

MICHELIA MEDIOCRIS Dandy
VERNALULAR NAMES: Giổi xanh, Giổi tanh
FAMILY: MAGNOLIACEAE

Morphology

A large evergreen tree, 25-30m in height and 70-80cm in diameter. Trunk straight, cylindrical. Bark grey, inner bark brownish-yellow, with stinking smell. Twigs tomentose, leaving stipule scars and bearing scattered round lenticels. Leaves simple, alternate, irregularly fixed on branches, leaf – blade coriaceous, glabrous, 8-20cm long and 5.5cm wide, oblong – ovate, tip with a short point, base round or cuneate. Lateral veins 10-20 pairs. Petiole 1-2cm long, glabrous, without scars. Stipules free, setaceous outside. Flower-bud enclosed by 3 caducous bracts. Flower solitary, terminal or opposite leaf. Pedicel 3-3.5cm long, tomentose. Sepals and petals not distinctive. Stamens numerous, connective with a short point. Carpels numerous, tomentose. Stamens and ovaries spirally arranged on a tomentose, cylindrical receptacle (androgynophore). Fruits compound, 10cm long when mature; follicle oblong – ovate, 22mm long and 13mm wide, with many stomata, dehiscing by a cover.

Distribution and ecology

An endemic species to Vietnam, distributed in hilly or mountainous regions, from 400 to 1,000m asl. In dense primary or secondary tropical and subtropical evergreen forests of northern and central provinces such as: Lao Cai, Nghe An, Ha Tinh, Kon Tum and Gia Lai. Usually mixed with *Michelia faveolata*, *Pelthophorum ferrugineum* and *Aglaia gigantean*, sometimes forming a dominant stand. Light-demanding and rather fast growing tree. Natural coppice-regeneration are good under thin forest cover. Flowering in Aril, fruiting in October.

Uses

Sapwood and heartwood distinctive, the latter is yellow. Timber very hard, texture fine, easy to work, rarely curved or sliptted after seasoning and resistant to termites and insects. Used in construction, boat and furniture-making. Seeds perfumed, used as a spice and medicaments for fever and bellyache.

Data sources: Vietnam Forest Trees (FIPI 1996)

MACHILUS ODORATISSIMA Ness
VERNACULAR NAME: Rè vàng
FAMILY: LAURACEAE

Morphology

A medium or lager-sized tree, up to 30-35cm in height and 40-60cm in diameter. Trunk straight, with few branches. Crown small. Bark greyish-white with numerous lenticels. Inner bark yellowish, 8-10mm thick, aromatic. Twigs brownish, glabrous. Leaves simple, alternate, coriaceous, lanceolate, 12cm long and 3.5cm wide, tip slightly acute, base cuneate, glabrous on both surfaces. Lateral veins 7-10 pairs. Petiole lanky, 7-15cm long. Inflorescence is a panicle, equal or longer than the leaf, tomentose at rachis-base. Flowers yellowish, bisexual.Perianth 6 lobes, equal, oblong, shortly tomentose outside. Staments 9, in 3 circles, 6 outer stamens without glands, 3 inner ones biglandular at the base. Anthers 4-locular. Staminodes 3. Ovary globose and glabrous, style long, stigma globose or subglobose, fruit globose 10-20mm in diameter, calyx persistent and speading, blackish-violet when mature, covered with white powder. Fruit pedicel reddish.

Distribution and ecology

Distribution in Vietnam, Laos, Cambodia and India. In Vietnam found in Lao Cai, Yen Bai, Cao bang, lang Son, Bac Thai, Vinh Phu, Quang Ninh, Ha Nam, Ninh Binh, Thanh Hoa, Nghe An, Ha Tinh, Dong Nai and Kien Giang Provinces, in primary, as well as secondary forests. In primary forests, this species is often mixed with *Celtis australis, Cinnamomum parthenoxylon* and *Lithiocarpus ducampii*, and in secondary forests often mixed with *Canarium album, Ormosia balansae* and *Pelthophorum ferrugineum*. Light-demanding tree, growing on deep, humus-rich and well-drained soils. Fast-growing, annual height-increment and annual diameter-increment are 1m and about 1cm respectively. Natural and coppice-regeneration are good. Flowering in May-June, fruiting in October-November. Tree gives a huge number of fruits and seeds. Can be successfully propagated by one year old seedlings.

Uses

Timber with distinctive heartwood and sapwood: Heartwood yellowish, sapwood white, rather durable and heavy (density 0.87), easy to work, rather resistant to termites and insects, used in construction or in precious furniture-making.

Data sources: Vietnam Forest Trees (FIPI 1996)

ERYTHROLOEUM FORDII Oliver
VERNACULAR NAME: Lim xanh
FAMILY: LEGUMINOSAE
SUBFAMILY: CAESALPINIOIDEAE

Morphology

An evergreen, big tree, 20-25m in height, 70-90cm in diameter. Bole straight, cylindrical. Crown dense and widely spreading. Bark reddish brown with many lenticels, when old splitted in to large scales. Leaves bipinnate compound, 3-4 pairs of secondary petioles, each bears 9-13 leaflets. Leaflets alternate, ovate; top mucronate, base rotund. Veinules obvious on both faces. Leaf blade glabrous. Inflorescence a compound raceme, 20-30cm long. Much branched into spikes. Flowers small, numerous, white-yellow. Sepals 5, connate into a campanulate tube with 5 boles. Petals 5 narrow and long, margin ciliate. Stamens 10. Ovary connected to the calyx-base. Fruit oblong, about 20cm long and 3-4cm wide. Seed flat, blackish-brown, lignified, canaliculated around the seeds.

Distribution and ecology

Distribution in South of China and North of Vietnam. In Vietnam found from northern boundary province to Quan Nam-Da Nang province, below 700m als. Sparsely met in Vinh Phu, Lang Son, Bac Thai, Quang Ninh and Ha Bac province and rather common in Thanh Hoa, Nghe An, Ha Tinh and Quang Binh provinces. In some places they are concentrated in dominant stands with 60-70% of the tree species component (Tien Yen-Quang Ninh, Huong Khe-Ha Tinh, Le Ninh – Quang Binh). Usually mixed with *Gironniera subaequalis, Madhuca pasquieri, Pygeum arboretum, Canarium album, Rhaphiolepis indica* and *Pterospermum heterophyllum*. Shade-demanding when young and only regenerates well in shady and cool forest, medium light, especially under canopy of *Liquidambar formasana* (in Lang Son, Thanh Hoa and Ninh Binh provinces).

The tree likes clay soil or loamy and deep soil. Coppice regeneration is poor. Flowering in April-May, fruiting in October-November.

Uses

Sapwood and heartwood distinctive, the first is greyish, the second is yellow-blue, turning dark brown. Texture spiral, heavy with density of 0.9-1.0. Timber precious, very durable, and used in construction, ship-building, for plank, sleeper and furniture-making. Bark contains much tannin, used for tanning or dyeing.

Data sources: Vietnam Forest Trees (FIPI 1996)

CINNAMOMUM OBTUSIFOLIUM Ness
VERNACULAR NAME: Re gừng
FAMILY: LAURACEAE

Morphology

A large evergreen tree. Trunk straight, 20-30m in height and 50cm (or more) in diameter. Bark grey-brown or dark brown. Inner bark brown or yellowish, 5-6cm thick, brittle and with aromatic smell of cinnamon. Twigs brown, quadrangular, then cylindrical. Leaves simple, alternate or subopposite, coriaceous, lanceolate or oblong – ovate, 9-30cm long and 3.5-9cm wide with long or short, obtuse point at tip, base cuneate, margin entire, glossy on both surfaces. Nerves arch-shaped, tri-nerved, the two laterals enlongated to the apex; venules reticulate. Petiole 12-20mm long. Inflorescence is a panicle, axillary, consisting of many cymes, 20-25cm long. Flower bisexual, middle flowers are large and their pedicels longer than those of lateral flowers. Perianth 6 segments, oblong, tomentose on both sides, 2.5 -4mm long. Stamens 9, arranged into 3 rings, staminodes 3, anthers 4 –locular. Ovary ovoid, glabrous, style as long as the ovary, stigma rather gross. Fruit a berry, ovoid, 1cm long, perianth persistent at the bases, black when mature.

Distribution and ecology

Distribution in Vietnam, Laos, India and China. In Vietnam found in Cao Bang, Lang Son, Vinh Phu, Ha Nam, Ninh Binh (Cuc Phuong National Park), Thanh Hoa, Nghe An, Ha Tinh, Dac Lac and Lam Dong provinces, in tropical evergreen forests below 800m als., on deep, sandy and well –drained soils. Often sparsely occurring at the high storey of forests. Natural regeneration is good under thin canopy of mother tree where there usually are many seedlings and saplings. Fast growing tree. In the forest of Huu Lung (Lang Son province), this tree increases in 1m height and over 1cm in diameter annually. Flowering in November-December, fruiting in March –May.

Uses

Timber dark grey, then darker and darker; veins straight, texture fine, rather soft and medium heavy (density about 0.6), easy to work, but with poor resistance to rot. Can be used in construction and for furniture and agriculture tools. Essential soil can be distilled from leaf, root and trunk bark.

Data sources: Vietnam Forest Trees (FIPI 1996)

HOPEA ODORATA Roxb
VERNACULAR NAME: Sao đen
TRADE NAME: May khen hua, may thong
FAMILY: DIPTROCARPACEAE

Morphology

A big evergreen tree, up to 30-40m height and 60-80cm diameter. Bole cylindrical, 15-25m. Bark blackish brown, longitudinally fissured into many thin and rough pieces. Inner bark reddish brown, much fibrous. Twigs and petioles covered with grey stellate hairs, later glabrous. Leaves ovate, oblong or lanceolate, 8-14cm long and 3-6cm wide, apex short acute, base slightly unequal, lateral nerves 8-10 pairs, evident beneath, venules zigzagging, nearly parallel, stellate hairy on both surfaces and usually glandular at the axils of secondary veins on lower leaf surface. Petioles 12-18cm long. Inflorescence an axillary or terminal spike-panicle. Rachis whitish grey, 10-12 spikes in each panicle and 4-6 flowers in each spikes. Flowers subsessile, sepals 5, hairy in both sides. Petals 5, falcate serrate and hairy outside. Ovary hairy. Fruit ovoid, 7-8mm in diameter, with 2 developed wings, 5-6 long and 1-2cm wide.

Distribution and ecology

Distributed in India, Thai Lan, Lao, Cambodia and Vietnam. In Vietnam found in most provinces od southern Vietnam, from Gia Lai and Kon Tum and southwards. Also planted in Hanoi and Ho Chi Minh cities from the beginning of 20^{th} century. Grows gregariously in dense tropical evergreen forests, but after a long period of selective logging, it is only found in small groups or in solitude. Demands wet and deep soil. Natural regeneration is good under thin forest-cover. Flowering in February-March, fruiting in April-July

Uses

Timber greyish yellow, sapwood is lighter than heartwood. It is a good and valuable timber of Vietnam, resistant ti insects and termites. Usually in making of furniture, floors, railway sleeper, wagons and ship-building. Trunk contains much resins and gums; is planted as avenue shade-trees in many cities and towns of Vietnam.

Data sources: Vietnam Forest Trees (FIPI 1996)

CANARIUM ALBUM Raeusch
VERNACULAR NAME: Trám trắng
FAMILY: BURSERACEAE

Morphology

A big tree, up to 25-30m height. Trunk cylindrical, straight and late branched. Bark white, fissured in to small pieces when old, exuding white resin. Leaves imparipinnately compound. Leaflets oblong-ovate, 5-15cm long and 2.5-6cm wide, crustaceous, with many shining white scales beneath, apex gradually tapered and base unequal. Stipule awlshaped, caducous. Inflorescence racemonse, usually shorter than leaf. Flowers with short penducle, 0.2-0.3cm long, yellowish-white. Fruit and oblong-ovoid drupe, 3.5-4cm long and 2-2.5cm wide, yellow-green when mature. Seedlings with leaves which are very variable in shape: First, they are simple and deeply lobed, then they become entire and at last, imparipinnately compound, similar to the leaves of mature trees.

Distribution and ecology

Distribution in primary and secondary forests of most provinces in North Vietnam, particularly in Quang Ninh, Bac Thai and Vinh Phu, below 500m als. Usually mixed with *Erythrophloeum fordii, Coelodepas hainanensis, Hopea sp., Peltophorum tonkinensis, Pygeum arboretum* and *Gironniera subaequalis,* or growing in dominion of *Canarium tramdenum* and *Erythrophloeum fordii, or Canarium album and Hopea sp.* Fast growing and light-demanding tree. Natural regeneration good in secondary forests with forest –cover of 0.3-0.4. Flowering in January-February. Fruiting in June-July.

Uses

Timber greyish-brown, soft and light. Used for sawing-board, house construction and fuelwood. The resin is used for incense, canarium perfume oil and turpentine, being a raw material for paint and printing industries. Fruit edible or used in medicine against diarrhea, rheumatism and as disinfective. Seed contains edible oil.

Data sources: Vietnam Forest Trees (FIPI 1996)

Curriculum Vitae

Personal information

Name:	(Mr.) Vu Van Hung
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Date of birth:	July 27th 1971
Place of birth:	Hai Phong, Vietnam
Family status:	Married, two children

Education

2010 – Now	Ph.D. student, Department of Silvicultural and Forest Ecology, Goerg-August-Universität Goettingen, Germany
2001 – 2004	Master Student, Forestry University of Xuan Mai, Ha Tay, Vietnam: master degree
2001 – 2004	Student of Forestry University, Xuan Mai, Ha Tay, Vietnam: Forestry Engineer
1998 – 1990	Student of Forestry College of Quang Ninh, Vietnam: Forestry Technicican

Work experience

1991 – 1994	Sub-Forestry Inventory and Planning Institute (SUB-FIPI), Ministry of Agriculture and Rural Development (MARD), Vietnam. Main task was on forest inventory, Land Use Planning (LUP), and Land Allocation (LA).
1997 – 1999	Ba Vi National Park. Main task was on protection of fauna and flora, Land Allocation, and established plantation stands in the National Park.
2000 – 2010	Management Board for Forestry Projects (MARD), Vietnam. Main task was elaboration of technical guidelines (LUP, LA, seedling productivity, monitoring and evaluation), working with the counterparts and implementation field activities.

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