From *Imperata cylindrica* Grasslands to Productive Agroforestry

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The Tropenbos-Kalimantan Series presents the results of studies and research activities related to sustainable use and conservation of forest resources in Indonesia. The multi-disciplinary MoF-Tropenbos Kalimantan programme operates within the framework of the international programme of Tropenbos International. Executing Indonesian agency are the Forest and Nature Conservation Research and Development Centre, Bogor; and the Forest Research Institute, Samarinda; governed by the Forestry Research and Development Agency (FORDA). Other executing agencies include the International Centre for Research in Agroforestry Southeast Asia (ICRAF-SEA).

Wageningen University,
the Netherlands

Ministry of Forestry, Indonesia

CONTENTS

ABSTRACT

Conversion of an *Imperata cylindrica* ecosystem into an agroforestry ecosystem is a complex process. Integrated control of the *I. cylindrica* grass is needed in combination with planting deep-rooted pioneer tree species, a legume cover crop and annual food crops. *I. cylindrica* grasslands are generally poor in nutrients, but they are not necessarily poor from a soil biological perspective and may contain high densities of mycorrhizal spores. Experiments in the nursery and in the field were conducted to provide the knowledge needed to design and improve smallholder options for converting *I. cylindrica* grasslands into productive and sustainable agroforestry systems. Inoculation with mycorrhizal fungi (resting spores in 'Mycofer' belonging to *Glomus manihotis*, *Glomus etunicatum*, *Gigaspora rosea* and *Acaulospora tuberculata*), did not promote tree seedling growth in the nursery, but it leads to a significant increase in survival rate of the four tree species tested, once these were transplanted to the field. However, this rate increased by 6.5% only. Nursery inoculation of the trees did not have any positive effect on the subsequent growth of those trees that survived the critical early stage. There is no compelling need for the use of the inoculum of the type used in the nursery. The performance of three out of four selected tree species growing in the alang-alang grassland, and their capability to outshade the grass, mahogany (*Swietenia macrophylla* King, Meliaceae), sungkai (*Peronema canescens* Jack., Verbenaceae) and candle nut (*Aleurites moluccana* (L.) Willd., Euphorbiaceae) made them most suitable to be planted in those useless lands. Breadfruit or sukun (*Artocarpus altilis* Fosberg, Moraceae) proved itself unsuitable for the harsh conditions of large parts of the *I. cylindrica* grasslands. It only performed well in specific sites. The field experiments showed no statistically significant differences in tree growth linked to the method used for initial alang-alang suppression. Ploughing, herbicide use or the simple 'pressing' method all proved acceptable as part of the overall system used. Spraying herbicide and ploughing are the most efficient methods to reduce alang-alang biomass. Pressing is the cheapest method to prepare acceptable tree growth, but is less attractive for inter-cropping. As a cover crop, able to outshade alang-alang after one year, to prevent its recovery and to improve soil fertility at the same time, *Pueraria javanica* (Leguminosae-Fabaceae) is a good option. An overall tree-LAI ≤ 1 and an overall rate of tree-shading ≤ 40 % are conditions for maximal corn yields by inter-cropping in a matrix of diverse trees species. Mahogany and sungkai have a crown architecture and a root distribution apt to stimulate the establishment of an agroforestry system, because they are particularly suited to live together with annual plants. Candle nut, however, is more appropriate to reduce *I. cylindrica* grass by shading with its wide, dense hemispherical crown. Functional Branching Analysis (FBA) software can yield estimates of above ground biomass of mahogany and sungkai with an average standard deviation of 1 ± 0.34. While conversion of alang-alang grasslands into more productive and sustainable land uses is technically feasible, a broader approach including household level livelihood options may be needed to better understand the structure of the incentives needed to achieve real-world impacts of this research.

PREFACE

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Wageningen, December 2002

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1. GENERAL INTRODUCTION

1.1. BACKGROUND

1.1.1. *Imperata cylindrica* Grassland

While Indonesia's forests are gradually disappearing, the area of coarse grasslands, dominated by *Imperata cylindrica*, appears to increase. Reclaiming these grasslands for more intensive land use seems to be an obvious alternative to clearing new forest lands, but the driving forces for forest degradation and conversion cannot be easily deflected to the already degraded lands, for a number of reasons.

Imperata cylindrica (L.) Beauv. is a perennial grass, known as one of the most important weeds in the world. It is widely distributed in the tropics and sub-tropics (Mangoendihardjo, 1980a; Skerman and Riveros, 1990; Tjitrosoedirdjo, 1993). An estimated 500 million ha are covered by *Imperata* spp. throughout the world, 200 million ha of which in Southeast Asia (Martoatmodjoun, 1976). Common names of *Imperata cylindrica* are cogon grass, spear grass, blady grass, satintail or in Indonesia, alang-alang.

Garrity et al. (1997) discussed the data on area extent of alang-alang lands and proposed to distinguish between sheet or mega-grasslands up to 10,000 contiguous ha in extent, to micro-scale patches contained within individual fields. The CSAR (Centre for Soil and Agroclimate Research) accordingly estimated that the *I. cylindrica* grassland area in Indonesia in the early 1990's covered approximately 8.6 million ha (ca 4.5% of the land area). Among the islands, Sumatera and Kalimantan have the largest *alang-alang* areas, i.e. 2.13 and 2.19 million ha respectively (Garrity et.al., 1997). According to the Forestry Statistics of Indonesia 1996/1997, the total area of critical lands (usually dominated by *alang-alang* grass) at the beginning of *PELITA VI* (6th Five Years Plan) was 12.5 M ha; of which 3.7 M ha (30%) were inside the forest area and the remaining 8.8 M ha (70%) outside. Four years later, at the end of the year 2000, the total area of critical lands had increased to 23.2 M ha, consisting of 8.1 M ha or 35% inside and 15.1 M ha or 65% outside the forest area (Ministry of Forestry, 2001). Hence, during those four to five years deforestation almost doubled. The alang-alang grassland area did more than double during the same period. This was may be an impact by forest fires (see Priadjati, 2002), which increased alang-alang areas inside forestland. The Ministry of Forestry (2001) reported that the average national deforestation rate from 1985 to 1997 was 1.9 million ha per year.

Improper use of lands, shifting agriculture systems, logging activities, transmigration, over intensive food crop production and fires are the most frequent causes of land degradation. The spread of *I. cylindrica* is often linked to a loss of soil fertility. The grass, which blocks vegetation development effectively at lower fertility levels, gradually occupies an increasingly large area (Hairiah et al., 2001).

In many transmigration areas, alang-alang spread since most of the transmigrants abandoned their land after two to three harvests of food crops, when soil fertility became poor and there were better opportunities for income generation off-farm. Inside the forest area, alang-alang invasion may be the result of intensified forms of shifting cultivation, where land pressure and frequency of fires has reduced the fallow periods and/or prolonged the cropping period till the balance between woody plants regrowth and grass in fallow vegetation shifted towards the grass. As long as it is practised at traditional intensity, shifting agriculture is sustainable and allows the regeneration of woody perennials from stumps as well as seeds from nearby more mature stands (Van der Wall, 1999; Kippie, 2002).

What is happening in reality is that the sequence of slash-and-burn or over-intensive sedentary agriculture goes in regression. The sustainable sequence is as follows (open arrows ecological succession):
[Forest ⇨ slash-and-burn ⇨ cropping ⇨ secondary forest ⇨ slash-and-burn ⇨ cropping
⇨ secondary forest ⇨ slash-and-burn ⇨ cropping <stable cyclic repetition>].
Van der Wall (1999) showed, that given the right rotation and harvest frequencies, a stable cycle can become established after four to five successive slash-and-burn operations from the original intervention in the forest. Kippie (2002) took this to be the basis of the Ethiopian Gedeo system, which has been sustainable over millennia.
The regressive sequence, when the process is excessively accelerated by coming back too soon, and intensified by over-harvesting, is as follows (black arrows ecological regression):
[Forest ⇨ slash-and-burn ⇨ cropping ⇨ secondary forest ⇨ slash-and-burn ⇨ cropping ➔ low secondary vegetation ➔ slash-and-burn ➔ low yield crop ➔ shrubs and weeds ➔ slash-and-burn ➔ very low yield crop ➔ alang-alang ➔ abandonment ➔ blocked ecological development].

Ecologically, alang-alang vegetation is a blocked development phase in ecosystem development. A blocked ecosystem or a blocked phase is a phase that inhibits the processes leading to the next development phase. The blocked phase can be based on the absence of viable stumps, depletion of seed banks, reduced inflow of seed from the surrounding landscape and/or soil conditions that do not allow for rapid growth of seedlings to a stage where they can replace the grass. For example, in Ivory Coast development is blocked by lianes after several cycles of shifting cultivation (Kahn, 1982 *ex* Oldeman, 1990; Oldeman 2002). Indonesian farmers used this mechanism. In several places in Java, bamboo phases in village forests block development as long as the farmers like. Bamboos protect against erosion and they yield income by selling the wood, when a slash-and-burn field for home cropping is opened. After cropping, bamboos re-invade the field by vegetative shoots and protect it again until the next cycle (Oldeman and Soemarwoto, 2002; pers.comm.). On the contrary, alang-alang vegetation is a useless form of blocked ecosystem. In this case, ecosystem conversion is required. Solutions must be found to break open the alang-alang ecosystem. Our study tests various ways of breaking open the alang-alang ecosystem, so that the interacting components of a new development phase can establish an ecosystem that will replace alang-alang.

In the following paragraphs the regressive sequence will be considered in detail, with a view to explain it and to find a base for its correction and conversion into a useful ecosystem that is again dynamically sustainable. In view of the rural situation in East Kalimantan, where capital is scarce, and also with regard to the conservation of soil, water and biodiversity in this rich biological area, the present study is then defined in terms of biodiversity in agroforestry systems. Intentionally, the orientation upon intensification with high chemical and physical subsidies (chemicals and machines) and monocropping with highly specialised crop races is left aside.

1.1.2. *Imperata cylindrica*: The Plant

Imperata cylindrica belongs to the grass family Poaceae (Gramineae), tribe of the Andropogoneae, sub-tribe Saccharinae. Indeed, seen from afar it vaguely resembles sugar cane (*Saccharum album*) or upland rice (*Oryza sativa*). The genus *Imperata* is composed of two sub-genera, *Imperata* and *Eriopogon*. The sub-genus *Imperata* has only one species, *Imperata cylindrica*, whereas the sub-genus *Eriopogon* has seven species, *I. converta*, *I. brasiliensis*, *I. brevifolia*, *I. minutiflora*, *I. tenuis*, *I. cheesemani*, and *I. contracta* (Eussen, 1980). Hubbard et al. (1944) divided *I. cylindrica* into five varieties, *major*, *africana*, *europea*, *condensata*, and *latifolia*. Variety *major* is predominant in Asia, Australia, east tropical Africa and India (Eussen, 1980; Garrity et al., 1997).

I. cylindrica is a perennial grass which produces loose to compact tufts with erect culms (10 to 280 cm long) arising from tough, branched, whitish, creeping rhizomes. Most rhizomes are found in the upper 40 cm of the soil profile but they can grow to depths of more than one metre. The inflorescence is a cylindrical, spike-like panicle, 3-60 cm long and 0.5-2.5 cm wide, consisting of many spikelets surrounded by hairs, which give the inflorescence a silky, white appearance.

The grass has a C4 photosynthetic pathway, and so is well adapted to the hot open climatic conditions in several countries of Africa, South and South-east Asia. The grass invades a wide variety of natural habitats such as desert dunes, wetlands, savannahs and forests, where it can prevent the installation of other plant species (Lippincott and McDonald, 1996) and so block its ecosystem to further development. *I. cylindrica* tolerates burning by rapid regrowth from the rhizomes protected in the soil.

I. cylindrica propagates by seed and vegetatively by the extensive rhizome system. The plant is prolific. It produces abundant airborne seeds, up to 3,000 per plant. This enables dispersal and colonisation over long distances. Flowering is most common in the dry season and mostly occurs after stress, such as burning, cutting or drought. It also spreads by means of underground rhizomes, which proliferate in the soil giving rise to shoots at 25 to 50 cm intervals. Rhizomes fragmented by cultivation can produce more than 350 shoots in six weeks and a ground cover of 4 m^2 in 11 weeks (Eussen, 1980; NRI, IRRI and ICRAF, 1996). Due to its teeming propagation by abundant airborne seeds and vigorous rhizomes, this grass colonised huge areas and forms the blocked ecosystem mentioned.

Fire is an important ecological factor in the alang-alang grassland ecosystem. It helps to slow-down the natural succession to shrubs and/or secondary forest vegetation and is a major handicap in agroforestry options for alang-alang grassland rehabilitation (Wibowo et al., 1997). During the dry season, alang-alang is very dry and highly flammable. Therefore, trees that have been planted in grassland can be killed by alang-alang fire. The ecological blocking mechanism hence is fire eliminating other species and helping alang-alang. Thousands of hectares of reforestation trees burn every year especially on *I. cylindrica* grassland (Sagala, 1988). A study in Benakat, South Sumatera showed that *I. cylindrica* dominated such burnt-over areas (Wibowo et al., 1997)

Many methods of *I. cylindrica* control have been studied and published by authors, such as Soedarsan (1980), Mangoendihardjo (1980b), Arif and Subagio (1980), Skerman and Riveros (1990), Terry et al., (1997) and Macdicken et al., (1997). There are four simple main methods, i.e. mechanical (physical), chemical, biological and ecological control. However, integrated control, i.e. control based on interactions and mechanisms proper to the ecosystem it self, is more promising because it is self-reinforcing.

Linked to the C4 photosynthetic pathway, *I. cylindrica* is considered to be a relatively intolerant to shade. Shading of *I. cylindrica* results in reduced carbohydrate storage, reduced rhizome and tuber production, reduced dry weight of the shoots, increased inability to find optimal resources for survival, increased susceptibility to herbicides and decreased vigour and/or regeneration (Macdicken et al., 1997). Eussen (1981) found that the relative growth rates (RGR) of *I. cylindrica* shoots and rhizomes over a period of two to six months were reduced by 50% by an 80% reduction of full sunlight. In an experiment using unshaded plots versus 50% shade, and 75% shade, Moosavi-Nia and Dore (1979) found strong reductions in shoot dry weight, rhizome dry weight and total carbohydrate content of rhizomes of *I. cylindrica* grown in shade.

1.1.3. Vesicular-Arbuscular Mycorrhizae and Nutrient Supply

Associations between fungi and plant roots are well known as mycorrhizae, mycorrhizal associations or mycorrhizal symbiosis. The term of mycorrhizae is derived from the Greek μνκος (mycos, toadstool) and ριςα (rhiza, root) (Oldeman, 1990). The associations most often benefit both, fungi and plants. Mycorrhizal fungi have no chlorophyll, and receive photosynthates from the tree they live on. In return, they provide products and services to that tree. Some important interactions can be enumerated as follows (Oldeman, 1990, p 219).

- The hyphae of the fungus increase the water-absorbing root surface manifold and may increase water absorption by trees by a factor of 100% or more.
- In the hyphae, a stock of nutrients is available to the tree, and in the tree there is one for fungus. Both organisms buffer each other.
- The fungus can mobilise elements in the soil that the tree cannot absorb otherwise.
- The fungus occupies the space in and around the roots that can otherwise be occupied by pathogenic fungi, and so protects the tree.

- Mycorrhizal fungi can produce antibiotics that protect the tree-partner against pathogens.
- The fungus may absorb heavy metals in polluted soil, accumulate and immobilise them in the hyphae so that they do not reach and poison the partner tree (Morselt et al., 1986 *ex* Oldeman, 1990).
- The fungus often synthesises special nitrogen compounds, such as vitamins or amino acids that the roots do not produce.

Smith and Read (1997) divided the mycorrhizae on the basis of their fungal associates into seven types: Vesicular-Arbuscular mycorrhizae (VA mycorrhizae), Ectomycorrhizae (ECM), Ectendo-mycorrhizae, Arbutoid mycorrhizae, Monotropoid mycorrhizae, Ericoid mycorrhizae and Orchid mycorrhizae. VA mycorrhizae are formed in the roots of an extended variety of plants by aseptate, obligately symbiotic fungi. These associate by means of intracellular colonization by fungi from the order of the Glomales (Zygomycetes), while the other six types of mycorrhizae are formed by septate fungi in Ascomycetes and Basidiomycetes. Those types of mycorrhizae form the association also by means of intracellular colonization, except Ectomycorrhizae.

VA mycorrhiza are also known as Arbuscular mycorrhizae, since vesicles are not formed by all members of the Glomales (see Berch, 1987; Walker, 1992). However, according to Smith and Read (1997), the majority of species now described form both arbuscules and vesicles. The arbuscules occur within the cortical cells, whereas vesicles occur within or between them. A Vesicular-Arbuscular mycorrhiza has three important components: the root itself, the fungal structures within the cells of the root and an extra radical mycelium in the soil.

VA mycorrhizae were first recognised and described in the last decades of the nineteenth century by scientists working in the Bogor Botanical Garden in Indonesia. They were shown to be ecologically obligate symbionts of a very wide range of plant species of Bryophyta, Pteridophyta, Gymnospermae and Angiospermae (Smith and Read, 1997). The diversity of plant species forming these mycorrhizae is considerable, not only taxonomically, but also as to life form and geographical distribution. Herbaceous plants, shrubs and trees of temperate and tropical habitats may all form VA mycorrhizae. Only a few families and genera of plants do not generally form VA mycorrhizae. Such associations may show a particular form of specificity, shown by Smits (1994), who demonstrated that maximal survival and biomass production were reached in the combination of one dipterocarp species, one fungal species and one soil type. In mycorrhizae, there is no evidence of classical one-to-one obligate specificity between one phytobiont species and one mycobiont species in all circumstances, as sometimes found in phytopathology. Hiemstra (1995 p. 159), however, evokes the concept of a “disease triangle” as originally postulated by Agrions in 1988.

The lack of specificity in the relationships has important consequences for ecological interactions in plant communities. The symbiosis is biotrophic and normally mutualistic, the long-term compatible interaction being based on bidirectional exchange of organic and mineral substances between the symbionts and between each symbiont and the environment, as in the case of exudation of sugars or organic nitrogen compounds by leaves or root hairs (Oldeman, 2002).

Morton and Redecker (2001) described the taxonomic structure of the Order of the Glomales (Table 1.1).

Table 1.1. Taxonomic structure of the Order of the Glomales (after Morton and Redecker, 2001). Numbers of species in each genus, namely *Glomus*, 85; *Acaulospora*, 31; *Entrophospora*, 4; *Gigaspora*, 5; *Scutellospora*, 29; *Archaeospora*, 3 and *Paraglomus*, 2 were taken from the INVAM website. http: invam.caf.mvu.edu/myc_info/taxonomy/Authors/Authors.htm

Order	Family	Genera
Glomales	Glomaceae	*Glomus*
	Acaulosporaceae	*Acaulospora*
		Entrophospora
	Gigasporaceae	*Gigaspora*
		Scutellospora
	Archaeosporaceae	*Archaeospora*
	Paraglomaceae	*Paraglomus*

The essential functions of mycorrhizal fungi are to absorb nutrients in inorganic and/or organic form in soil and to translocate them or their metabolites to the symbiotic roots through the extensive vegetative mycelium. The external hyphae of VA mycorrhizal fungi can absorb non-mobile nutrient (P, Zn, Cu) from the soil and translocate them rapidly to the phytobiont (Mosse and Hayman, 1980; Harley and Smith, 1983). Therefore, the function of mycorrhizal fungi in absorbing nutrients is optimal in low nutrient availability (Smith and Read, 1997; Onguene, 2000).

Interactions between mycorrhizal development and fertilisation are still in debate. Newton and Piggot (1991), claimed that fertilisers and mycorrhizae are incompatible. Another finding was that fertilisers harm mycorrhizal fungi (Keyzer 1993). Smits (1992), however, reported that application of fertiliser after establishment of abundant ectomycorrhizae on root systems in cuttings of dipterocarp species has no negative effects. Further, Omon (1999) reported that inoculation of *Amanita* sp. in combination with application of a dosage of 100 mg NPK fertiliser resulted in a significantly higher percentage of *Shorea leprosula* cuttings being infected by mycorrhizae. Again, Omon (2002), reported that NPK fertilisation did not significantly affect the percentage of mycorrhizal roots. Even an application of NPK with 200 mg/cutting of *S. leprosula* in the greenhouse did not depress the mycorrhizal development.

Most soils in the tropics are classified as poor in nutrients, strongly acid with high clay and exchangeable aluminium contents, and low levels of available phosphorus and micro-nutrients (Sanchez and Salinas, 1981). The major input of mycorrhizal associations in the tropics would be to improve access to scarce soil nutrients, especially phosphorus and other slowly diffusing nutrients such as zinc, copper, boron, and molybdenum. Therefore, in most tropical soils, very few woody species of tropical trees are non-mycorrhizal (Alexander, 1989; Janos, 1980).

Forest disturbance by commercial logging and shifting cultivation may reduce or even eliminate mycorrhizal fungi from forest sites (Alexander et al., 1992; Reeves et al., 1979; Smits, 1994). Reduction of indigenous mycorrhizal fungal population has negative repercussions on the establishment of new man-made forest or reforestation activities, particularly in degraded grasslands. Therefore, the idea has often been put forward that tree seedling performance can and should be boosted by addition of a mycorrhizal inoculum.

Mycofer is a mycorrhizal inoculum created by Forest Biotechnology Laboratory, Inter University Centre of Biotechnology, Bogor Agricultural University. The inoculum, a semi commercial product, contains isolates of four species of vesicular-arbuscular mycorrhizal fungi, i.e. *Glomus manihotis*, *Glomus etunicatum*, *Gigaspora rosea* and *Acaulospora tuberculata*. These fungi are known to stimulate tree growth in low soil fertility condition (Setiadi, 1996; Prematuri, 1995; Prematuri and Dodd, 1997). The Mycofer was tested in this study for its ability to promote tree growth on degraded *I. cylindrica* grasslands in a transmigration area.

1.1.4. Agroforestry Systems and Technologies

Originally, organised land use most generally was a transformation of forest into a multi-species system providing all human necessities from one “field” or “plot”. The motor of all these systems, of which many survive in Indonesia (e.g. Michon, 1983) was natural biodiversity as a driving force of ecological interactions that ensured both the protection and the production of these systems. According to Kippie (2002) traditional farmers give priority to the aspect of protection against ecological excess factors (drought, proliferation of insects, wind, erosion) over boosting production, because they know and fear the consequences of hunger and misery when the system has no maximal sustainability and so may collapse in any excessive season.

In traditional development, population pressure brought specialised crops everywhere to some extent. In Indonesia, the rice fields (*sawah*) as food reservoirs, however, always had a sustainable and protected counterpart in the form of village or home gardens (*kebun, pekarangan*), as a life insurance in case of the misharvest of rice. Some examples are *Kebun-Talun and Pekarangan* in West Java (Widagda et al., 1984), *Damar* Gardens in Krui, Sumatera (Torquebiau, 1984), Multi Storied Gardens in West Sumatera (Michon et al., 1986), Rattan Gardens, *tajar hidup* (Bratawinata and Sardjono, 1988), and *Lembo* (Sardjono, 1995) in East Kalimantan.

In industrial parts of the world, specialisation became the rule for all production, mixed lands now being restricted mostly to decorative gardens, parks and nature reserves and more recently roadsides. This specialisation leads to the differentiation of agriculture, horticulture, forestry, cattle raising and all specialised forms of these. It was as a reaction to overspecialisation, so expensive as to be practically out of reach of tropical farmers, being very costly in terms of protection by pesticides and earthworks, and in general being so risky ecologically as to need an infrastructure of buildings to conserve reserve stocks of food, that the new concept of agroforestry arose.

This concept of agroforestry, as generally accepted today, was launched by Dr.Kenneth King in 1978 at the 8th World Forestry Congress in Jakarta, Indonesia. It was defined as a sustainable land management system which increases the overall yield of land, combining the production of crops (including tree crops) and forest plants and/or animals, simultaneously or sequentially, on the same unit of land, and applies management practices that are compatible with the cultural practices of the local population (King and Chandler, 1978). Later, many concepts were introduced (Lundgren, 1982; Vergara, 1982; Nair, 1983; 1985; Nair, 1993 *in* van Noordwijk and Tomich, 1995). Generally, they refer to a dynamic, ecologically and economically based mixed land use system that combines agricultural crops and tree crops in a multi-storied vegetation structure, simultaneously and/or sequentially.

Further, Nair (1987) distinguished between "agroforestry systems" and "agroforestry technologies". Where agroforestry systems consist of extensively used agroforestry practice(s) or traditional agroforestry; agroforestry technologies include improvements or innovations mostly through scientific intervention that can be applied with advantage for the management of the systems. Agroforestry technologies are, for instance, improved fallow, integrated *taungya*, hedgerow inter-cropping (alley cropping) or multipurpose trees on farmlands.

Agroforestry was claimed to solve low production and land degradation and in that way contributing to productivity and sustainability. As a component of agroforestry, many trees or leguminous cover crops can fix nitrogen, enriching the soil when their residues decompose. Trees also improve the poor soil by means of decomposing leaf litter and adding nutrients to the soil. Deeply-rooted woody plants are claimed to absorb nutrients from the sub-soil, bring them up to the surface and return them to the soil as litter, where they become available to other agroforestry components, such as crops. On sloping areas, contour row planting of trees may form biological terraces naturally. These hedgerows have an important role in reducing soil erosion as well as conserving soil fertility. Hence, establishment of an agroforestry system on degraded alang-alang lands means building a new ecosystem, ecologically sound and sustainable (Oldeman, 1983; 1990). Note that this contrasts with the gradual transformation and management of the natural local ecosystem, as traditional farmers do (Neugebauer et al., 1996; Oldeman 2002).

Nair (1983, 1985) stated agroforestry systems to be a solution in conserving the ecosystem, offering at the same time sustained production from the land in a form compatible with the socio-cultural aspirations and economic conditions of the farmer. They allow production of food and wood products at the same time from the same piece of land, not overly dependent on costly inputs. In such agro-ecosystems, trees and other components all interact. Interactions, among which supposed competition, between the agroforestry components occur both above and below ground level particularly in the distribution of water, nutrients and energy (photosynthesis above-ground, respiration below-ground). If managed well, interactions will optimise this distribution and be favourable to all components by reciprocal reinforcement (e.g. see Raintree, 1983). The web of interaction among trees, crops and other organisms, the species composition, and how far the interactions affect the tree and crop yield are not fully known yet. Such complex systems are inherently unpredictable, because they adapt to their changing environment by incessantly changing their interactions (Rossignol et al., 1998; Oldeman, 2002). However there are certain interactions, which always occur. By identifying these, we may arrive at growing trees and crops in harmony, in a system that both is biologically sustainable and provides competitive returns to labour.

In other words, the aim of agroforestry technology is the manufacturing of new, complex ecosystems, which use natural factors and interactions rather than artificial inputs to optimise the functions of green production, land protection, system sustenance and consonance with the local human society. If the land is much degraded and natural ecosystem development is blocked (see above, par 1.1), this manufacture entails starting up a completely new succession against the blocking forces of strong, but useless and degraded ecosystems such as alang-alang grasslands.

In Indonesia, agroforestry technologies have been implemented in several reforestation and re-greening programs inside and outside forest areas. They were also used in man-made forest establishment or industrial forest plantation by means of Social Forestry Programs. Tiwari (1983) defined Social Forestry as “the science and art of growing trees and/or other vegetation on all lands available, in- and outside the forest, with intimate involvement of the people and more or less integrated with other operations, resulting in balanced and complementary land-use with a view to provide a wide range of goods and services to the individuals as well as the society”.

The concept of social forestry was implemented in man-made forest establishment since decades, mainly in Java. The program was executed by means of *taungya* or *tumpangsari* system and was known as the *Perhutanan Sosial* program. In this program, landless people living inside or around a forest area are allowed to grow food crops, fruit trees and fuel- wood in between rows of timber trees during the first two to three years after tree plantation. To extend the duration of *tumpangsari*, a new program was introduced, called *tumpangsari sepanjang daur*. In this new program, spacing of trees in the plantation was extended, so as to provide enough space for crop growing. Shade tolerant crops were introduced, so that the program can be implemented in a long life cycle of the timber trees. Indeed, *tumpangsari* in this way is developing towards a true multiple-rotation system (Neugebauer et al., 1996) and so is converging with the traditional systems (cf. Kippie, 2002).

Reforestation and re-greening programs, particularly outside Java, were not satisfactory as yet. They are running too slowly (about half the rate of deforestation) and they had little success. The possible causes were low seedling quality, neglected maintenance, drought, fire and low awareness of the local community of the purposes and benefits of the project. Less awareness in local communities is primarily due to lack of involvement in the program, both in planning and execution. Hence, programs for re-greening or rehabilitation of degraded land in particularly, have to be carried out with serious local community participation, since outside the forest area, the lands are privately owned.

1.2. PROBLEM STATEMENT

Surrounding the Wanariset I Research Station (MoF-Tropenbos Kalimantan Program), East Kalimantan, one finds large areas of alang-alang grasslands as described earlier. To the Northwest of the Station, there are several transmigration areas built 15 to 20 years ago. The grass occupied most of these since the transmigrants abandoned their land after two to three harvests of food crops, which initiated the regression sequence mentioned above.

Only very rarely did the villagers cultivate their alang-alang lands for annual food or cash crops. Some of the villagers did plant upland rice in protected forest areas, by means of slash and burn cultivation. A preliminary survey pointed out that the communities in these transmigration areas abandon their alang-alang grasslands because of the difficulties in erradicating the grass. Eradication consumes much labour and needs large amounts of capital. In addition, the soil inside the forest area is much more fertile than the soil under alang-alang grass. An effective way is needed to suppress the alang-alang grasses and to restore the soil fertility and biodiversity of the ecosystem.

Another important reason why the transmigrants left their grasslands is that there is an alternative opportunity to get cash income from the surrounding forest by means of illegal cutting and making *sirap*, a kind of roof made from the *ulin* or iron wood (*Eusideroxylon zwageri*). During this study, it becomes clear that nearly 50% of the villagers' income is derived from such forest activities. The problem then is whether it is possible to provide the villagers with sufficient income from their own land and a viable alternative for the people who currently enter the forest area for their livelihood. If productive and sustainable village land use is indeed technically possible, economically feasible and socially acceptable, it may create possibilities for better conserving the natural resources without negatively affecting livelihoods.

Under the blocked alang-alang ecosystem, soil fertility can range from poor to moderate. Santoso et al. (1997), reported that *I. cylindrica* occurs on a broad range of soil types and is not confined to the poorest soils. Soil conditions differed between three types of fallow vegetation: ferns, *I. cylindrica* and *Austroeupatorium inulifolium* in West Sumatera. However, no major differences were found in available P or exchangeable cation content between those soils under *I. cylindrica* and *A. inulifolium* (Cairns, 1994 *in* Santoso et al., 1997). In acid soil like *Ultisol*, major nutrients such as nitrogen (N) and phosphorus (P) are deficient. This soil type is dominant in Indonesia and also in the transmigration areas. As stated above, the present study does not concern costly industrial remedies like the use of high dosages of commercial fertilisers. In a healthy, unblocked ecosystem, nitrogen is fixed and made available in organic form by bacteria, and phosphorus is mobilised by mycorrhizal fungi. In the present study the nitrogen deficiency hence is addressed by inter-cropping with a legume cover crop bearing nitrogen-fixing symbiotic bacteria in its root nodules, and available phosphorus deficiencies may have to be corrected by inoculation with mycorrhizal fungi at the tree nursery stage. *I. cylindrica* grasslands can, however, contain a rich array of mycorrhizal fungi. Setiadi (1999) found that biodiversity of arbuscular mycorrhizal fungi was different among land uses in Indonesia. The number of spores of the *Glomus* types in a 100 g soil samples under alang-alang grassland was 280 and under cassava it was 216. Those numbers are almost 6 to 7 times higher than spores under forest (45) and agroforestry (37) land uses.

The temperament of tree species to be planted on degraded grassland, particularly their role in improving soil fertility must be considered. The trees should be pioneers: fast growing, nitrogen fixing, and drought tolerant species. The farmers' preference for tree species must also be taken into account, however.

Brook (1989) claimed that the effectiveness of using forest plantations in controlling *I. cylindrica* is based on the light requirement of the grass. Suitable tree species for alang-alang grassland reforestation must have wide, dense crowns, casting dense shade. The shading capability of trees depends on branching patterns and crown shapes which can be modelled using geometrical parameters (Oldeman, 2002) and can be numerically expressed by leaf area index, crown area index and average light intensity on the ground. Graphically, it is shown in two scale-drawings of a field transect, the profile diagram and the map of crown projections on the ground (Oldeman, 1974; Michon, 1983). Because they are drawn to scale according to measured data, these drawings or maps are quantitative documents, although they are not numerical.

Macdicken et al. (1997) made a comparison between tree crops and cover crops as sources of shade. Tree crops may have advantages over herbaceous cover crops since they simultaneously provide substantial economic products, wood in particular. In agroforestry systems, the use of shade to suppress alang-alang is an important step in the starting up of a vegetational sequence leading to the establishment of more economically useful vegetation.

Conversion of alang-alang grasslands into a productive agroforest, particularly on private land, must involve the owners of the land, either in planning or in executing activities.

1.3. FORMULATION OF THE STUDY

The study was initiated by carrying out a base line survey to assess the problems, options and expectations of the human communities, particularly those relating to land use and farming systems. At the same time, site exploration was done to determine the exact places where the field plots could be established. The results of the survey suggested to plant four selected tree species in three selected sites as a main research. The study consisted of two stages, a nursery research and a field experiment. This field experiment was on-farm research, fully designed and managed by the researcher with limited participation of the landowners.

A development study was executed in the subsequent year, also based on on-farm research. This study was, however, fully designed and managed by the respective farmers, so it is called an experiment designed by farmers. These on-farm experiments were expected to enhance the local community participation in converting their degraded alang-alang lands to more profitable and sustainable land use based on agroforestry technology.

Three methods of alang-alang grass management were implemented in this study, i.e. spraying the grass with a herbicide, ploughing or hoeing the ground by a hoe and pressing the grass by a weight log. Planting four tree species was expected to supply shade to prevent recovery of the alang-alang. A legume cover crop was grown as initial effort to improve soil fertility as well as to suppress the recovery of the grass. A mycorrhizal fungi inoculum was tested for it ability to accelerate tree growth on the grassland.

1.4. RESEARCH OBJECTIVES

The overall objective of the study is to provide the knowledge needed to design and improve smallholder options for converting *I. cylindrica* grassland into a productive and sustainable agroforestry system. The strong risks of repetition of a regression sequence towards a blocked alang-alang system necessitate great concern in view of sustainability. In order to achieve this overall objective with its indispensable corollary, it was necessary:

1. To study the role of Vesicular-arbuscular mycorrhizal fungi inoculum in accelerating growth of four tree species in an agroforestry system established on degraded *I. cylindrica* grassland
2. To understand the dynamics of mycorrhizal fungi, indigenous and inoculated species, in the research sites
3. To study the capabilities of four tree species to be grown on degraded *I. cylindrica* grassland, growing vigorously and finding a foothold among the grass
4. To evaluate methods of *I. cylindrica* control in relation to tree growth and biomass reduction of the grass
5. To study participation by local human communities in the establishment of agroforestry systems on degraded *I. cylindrica* grassland.
6. To study tree architecture, root distribution and to estimate biomass of tree species as components of the agroforestry system.

1.5. OUTLINE OF THIS THESIS

This thesis describes the conversion of degraded *I. cylindrica* grassland, a blocked phase of ecologically development, into productive, profitable and sustainable agroforestry systems. The thesis consists of three parts. The first part (chapters 1 and 2) provides background and a short overview on *I. cylindrica* grassland, regressive sequence versus sustainable sequence, mycorrhizal fungi association and agroforestry systems. Further information is characteristic of the research sites, both biophysical and socio-economical aspects.

The second part describes the results of the study in detail (chapters 3 to 5). Chapter 3 discusses the growth of four tree species in a degraded *I. cylindrica* environment after mycorrhizal fungi inoculation and under three methods of alang-alang grass management. This chapter also presents the dynamics of the mycorrhizal fungi during the research period. Chapter 4 explains the dynamics of alang-alang biomass, cover crop biomass and its contribution to the soil fertility as well as an intercropping system with annual food crops. Farmer participation in the establishment of agroforestry systems is also discussed in this chapter. In chapter 5, the discussion focuses on tree architecture, root distribution and biomass estimation of the four tree species planted in the agroforestry system.

Finally, the third part of the thesis (chapter 6) provides a general discussion and a conclusion with recommendations for further support for agroforestry designed by farmers.

2. THE RESEARCH SITES

2.1. LOCATION AND HISTORY

Study sites were distinguished according to the research phases. The nursery research and seedling preparation for field experiments took place at a nursery of the Wanariset I Research Station, located some 38 kilometres to the Northeast of Balikpapan in East Kalimantan, Indonesia (Fig. 2.1). The station belongs to the Forestry Research Institute of Samarinda, Forestry Research and Development Agency, Ministry of Forestry, Republic of Indonesia in co-operation with Tropenbos Kalimantan Project (MOF-Tropenbos Kalimantan Program). Field experiments were carried out in a transmigration area, some 20 to 27 kilometres to the Northwest of the Wanariset I Research Station on the road to Semoi/ Sepaku (see Fig.2.1). The field plots were established on farmers' lands in the villages of Semoi II and Semoi III. Reasons why these villages were taken as the research sites are discussed in the paragraphs 2.2, 2.3 and 2.4. Administratively, these villages belong to Sepaku Sub-District, Pasir District, East Kalimantan Province. The Sepaku town as capital of Sepaku Sub-District is located at 116°49'21" East Longitude and 00°54'44"North Latitude.

The distance of the villages to the sub-district capital, Sepaku town, is 10 to 12 km. To the district capital, Tanah Grogot city, it is about 200 km and to the provincial capital, Samarinda city, it is about 110 km. Due to the distance to Tanah Grogot city, the community in these villages has easier access to Balikpapan city (ca 60 km from the villages). In addition, the infrastructure and public transportation to Balikpapan are better and faster.

Semoi II and Semoi III are transmigration villages. These areas have been developed since 1978 and 1982, respectively. The transmigrants, who have been resettled in the areas, came from West and East Java. Approximately 500 household or 2263 transmigrants were resettled in Semoi II in 1978 and 384 household or 1518 transmigrants in Semoi III in 1982 (Departemen Transmigrasi, 1997).

The Semoi II village is located between the protected forest of "Bukit Suharto" and State Forest Enterprise of "Inhutani I" (Industrial Forest Plantation of Batuampar), while the Semoi III village lies between the protected forest of "Bukit Suharto" and the Forest Concession Area of "P.T. International Timber Corporation Indonesia (ITCI)". Formerly, these villages were parts of the PT ITCI concession.

2.2. BIOPHYSICAL ASPECTS

2.2.1. Landscape

The landscapes of Semoi II and Semoi III villages are dominated by sloping areas with scattered hills. Most of these areas are covered by grasses that usually grow after fire or slash-and-burn cultivation, i.e. *Imperata cylindrica* or alang-alang.

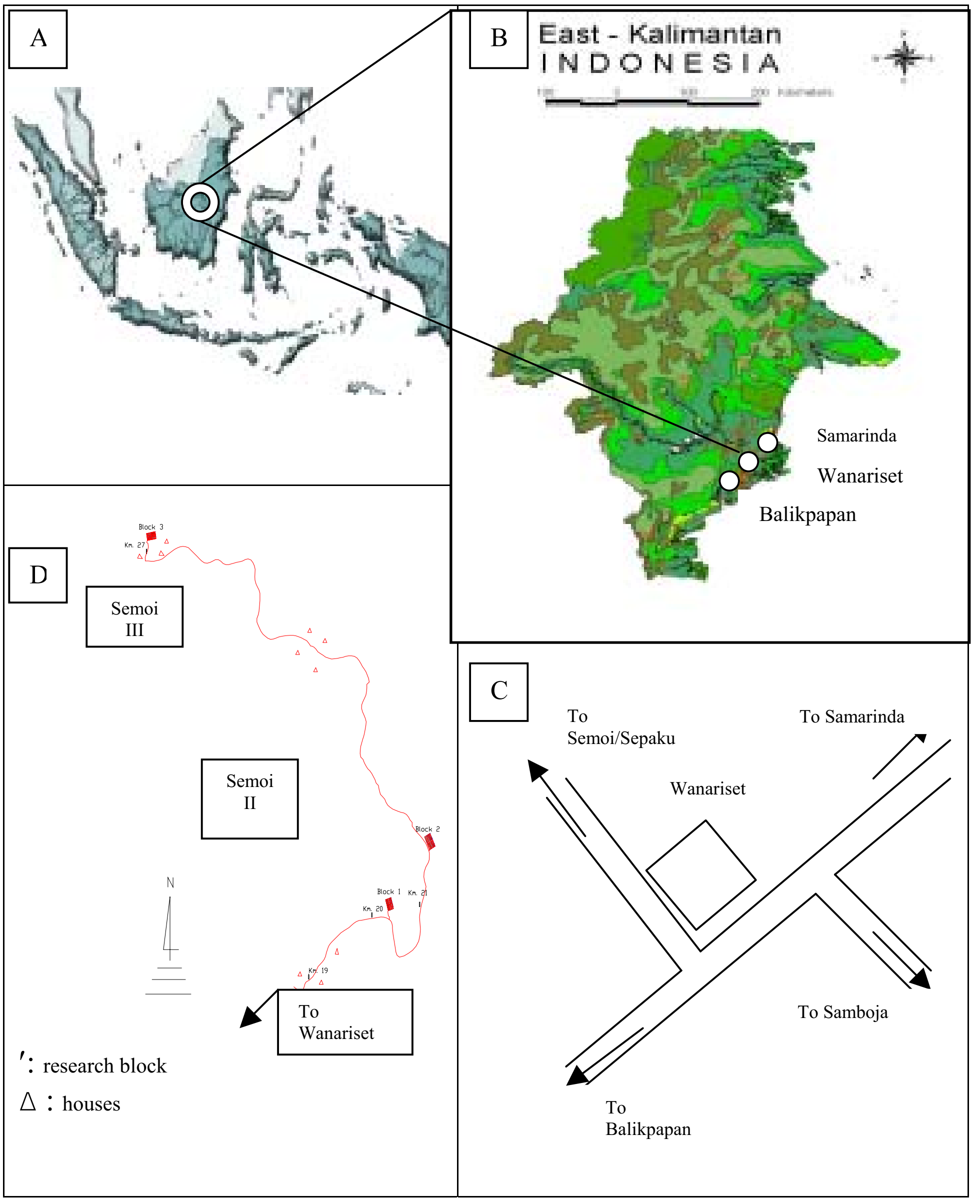


Fig.2.1. Map of the Wanariset I Research Station and Field Plot Situation in Semoi II and Semoi III Villages, East Kalimantan, Indonesia. A. Indonesia, B. East Kalimantan, C. Wanariset I Research Station and D. Research sites situation

We can also find some young secondary forests and bushfallow in a mosaic with smallholder pepper gardens. Surrounding the houses are home-gardens dominated by fruit trees. Annual food crops and vegetables are rare.

As in other transmigration areas, transmigrants in Semoi II and Semoi III were provided with three parts of land. The first, known as *Lahan Usaha I*, was a piece of land surrounding the house, with a size of 1 ha per transmigrant household. The second, called *Lahan Usaha II*, was a piece of land that is located rather far from the transmigrant settlement also with a size of 1 ha per transmigrant household. The third, *Lahan III*, consisted of some land areas prepared for new families derived from the recent households. Those *Lahan III* are managed by and under authority of the Village Heads. Generally, each new family will get 1 ha for free, for a settlement (house, home-garden and agricultural land).

Usually the communities in Semoi II and Semoi III use the *Lahan Usaha I* for home-gardens and pepper cultivation and almost all villagers left the *Lahan Usaha II* in the state of alang-alang grasslands or bushfallows. Only a few farmers use those lands as pepper gardens or for other crop cultivation.

2.2.2. Soil Types

Data on soils, geology and geomorphology of Semoi II and Semoi III villages are taken from RePPProt (1987). According to their detailed soil survey of the PT ITCI area (including the Semoi-Sepaku area), middle-late Miocene and early Miocene rocks dominate the geology in the ITCI area, with alternating layers of sandstone, claystone, mudstone and siltstone of varying thickness. The geomorphology is dominated by steeply dissected hills and hillocks (altitude between 10 to 300 m above sea level) with short and steep slopes and narrow crests and valley floors. According to the geological map of East Kalimantan by Addison et al. (1983), the Semoi areas developed on late tertiary sedimentary rocks.

The Semoi areas are dominated by *Ultisols* (USDA Soil Taxonomy) or *Alisols* (FAO/Unesco/ISRIC, 1988) with mixed clay minerals, consisting of kaolinite, chlorite/vermiculite and oxides of aluminium and iron (Voss et al., 1979; 1988; RePPProt, 1987 *ex* Van Bremen et al., 1990). In general, the nutrient status of the soil is low, in particular where the topsoil is thin or absent. This is mainly due to the low mineral reserves of the parent material from which these soils have developed.

2.2.3. Climate

According to RePPProt (1987), the climate in the ITCI area is classified as "Afw" (Köppen, 1931) i.e. a tropical rainy isothermal climate. The mean annual rainfall ranges approximately from 2000 to 2500 mm (Voss, 1982). Usually, the months of June through October have less rainfall than the remainder of the year. The monthly precipitation then is still more than 100 mm. Based on data collected by Agricultural Service Office of Pasir Regency, the rainfall in the Sub-District of Sepaku, in which Semoi II and Semoi III are located, was 1,884 mm in 1998 (BPS Kabupaten Pasir, 1998). Annual rainfall for the Pasir District from 1994 to 1998 varied from 1,259 to

2,643 mm, with an average over the five years of 2096 mm (BPS Kabupaten Pasir, 1998). The high variation is noteworthy.

The mean monthly temperature at Balikpapan over the period 1960 to 1975 was 27°C (RePPProt, 1987). In the Semoi areas, the average temperature during 1998 ranged from 29° to 31°C (Desa Semoi II, 1998; Desa Semoi III, 2000).

2.2.4. Vegetation

The natural vegetation in East Kalimantan consisted of tropical rainforests dominated by tree species belonging to the family of the Dipterocarpaceae, such as *Shorea* spp., *Dipterocarpus* spp., *Dryobalanops* spp., etc. (Whitmore, 1984). Large parts of the natural forest have been logged and are nowadays covered by secondary vegetation.

The vegetation in the Semoi II and Semoi III villages is dominated by very large areas of *Imperata cylindrica* (alang-alang) grass. Other vegetation types are young secondary forest and bushfallow with scattered old trees and dead wood of the Dipterocarpaceae, mainly *Shorea laevis* ("Bangkirai") and *Eusideroxylon zwageri* ("Ulin" or "iron wood"). Plate 2.1 presents a satellite image of Balikpapan and the surrounding areas, while Plate 2.2 shows a more detailed satellite image of the Semoi II and Semoi III areas between 0° 55' S Latitude; 116° 52' E Longitude and 0° 57' S Latitude; 116° 54' E Longitude). Both pictures, taken in 2000 show that the areas were at that time covered by grasses or shrubs or human settlements.

2.3. SOCIO-ECONOMIC ASPECTS

A base line survey has been conducted in the Semoi II and Semoi III villages before the field experiment was carried out. The results of the survey determined why these sites were chosen for the study area of converting alang-alang grass into productive agroforestry. The survey aimed to observe and to assess the land use and farming systems of the community as well as the farmers' problems and expectations. The survey was done in April and May 1999 (before the field plots were established).

Methods of the survey consisted of field observations, semi-structured interviews and PRA (Participatory Rural Appraisal). The purpose of the field observation was to get an overview of the land use and farming systems practised by the communities in those villages. Interviews within these communities aimed to delve into their problems and expectations at the household level, while the PRA also should elucidate the socio-economic conditions of the community at the village level.

Twenty respondents were selected randomly in each village, based on a list of households of the whole village. The interviews were carried out at the home of each selected respondent. The PRA was established with all groups of the communities in both the villages in order to obtain representative data. For this purpose, the community in each village was divided into 8 groups, each consisting of 5 to 7 members.

The groups are as follows:

1. Common community
2. Community leader (formal and informal)
3. Poor community
4. Average community
5. Rich community
6. Farmers
7. Women
8. Forest dwellers (persons, whose earnings are mainly derived from the forest)

In the following paragraphs the results of the survey will be discussed.

2.3.1. Land Use and Farming Systems

There are several land uses in the villages of Semoi II and Semoi III, namely human settlement and public facilities, homegarden and *ladang*, grass (alang-alang) lands and coal mining. *Ladang* is a piece of land located rather far from the farmer's house (in this case *Lahan Usaha II*), and usually cultivated with cash or perennial crops by slash-and-burn. Homegardens and *ladang* only occupy around 25 to 30% of the total lands in the villages, while alang-alang grasslands occupy about 55% of the Semoi II area and 54% of the Semoi III area. At the household level, where most of the respondents were true farmers, the size of the alang-alang grasslands ranged between 40 and 52% of the total.

Farming systems found in the areas mainly consisted of homegardens and *ladang* dominated by fruit trees and pepper gardens. Only a few farmers cultivated food crops such as maize and upland rice. As a consequence, most foods, such as rice and vegetables for daily consumption, have to be imported from the city of Balikpapan. The reasons why the villagers were not willing to cultivate, and abandoned their lands as alang-alang grasslands, are lack of capital, lack of labour, pig attacks, infertile soil, difficulties to control the grass, fire risk, uncertainty in product marketing, and the need of cash income. However, based on the author's assessment, the real cause was, the existence of an alternative to get cash income from the surrounding forest by means of illegal cutting and making *sirap*, a kind of roof made from the ulin or iron wood (*Eusideroxylon zwageri*).

On the one hand, farmers very rarely cultivated their alang-alang land for annual food crops. On the other hand, however, some of the villagers planted upland rice in the forest areas by means of slash-and-burn cultivation. From this reality, it can be concluded that the communities in these villages abandon their alang-alang or grassland since they could not eradicate the grass. This consumes much labour and needs large amounts of capital. In addition, the soil in the forest area is much more fertile than the exhausted soil under alang-alang grass.

2.3.2. Source of Income

Communities in the Semoi II and Semoi III have many ways to survive. Some of them get their livelihood from on-farm activities such as pepper gardens or the cultivation of upland rice and maize as well as from on-farm work as daily workers. Other people earn money from formal off-farm activities like teaching and trade. The important and significant sources of income of the communities in these villages come from the surrounding forest. Many people are involved in illegal activities, such as cutting, logging, sawmill, and making *sirap*. *Sirap* is a kind of roof made from the ulin or iron wood. According to the survey, nearly 50 % (47 % in the Semoi II and 46% in the Semoi III) of the villagers' income came from such activities inside the forest area. Table 2.1 shows the composition of community's income according to the sources in the Semoi II and Semoi III villages.

Table 2.1. Composition of the community's income in the Semoi II and Semoi III villages

Source of Income	Income (%)		
	Semoi II	Semoi III	Average
On-farm activities	32	38	35
Off-farm activities	21	16	18.5
Inside Forest activities	47	46	46.5
Total	100	100	100

Table 2.1 shows that income from on-farm activities in both villages is only 35 % of their total income, while income derived from the forest activities occupies the largest portion (46.5%) and off-farm activities contributed 18.5 % to the community's income.

2.3.3. Demography and Villages' Infrastructure

The population in the Semoi II and Semoi III villages was rather stable during the last two decades, from 1978 to 1998 (Table 2.2). The number of households in the Semoi II village increased, but the number of people decreased during this period (Departemen Transmigrasi, 1997 and Desa Semoi II, 1998). In the Semoi III village, both the number of households and number of people decreased between year 1982, when the village was founded and year 2000 (Departemen Transmigrasi, 1997 and Desa Semoi III, 2000). Probably, many young people left the area to establish them selves elsewhere and a number of households remigrated to their original home area on Java island.

Based on the population data and size of the areas, the current population densities in the Semoi II and Semoi III are 37.4 and 30.1 person km^{-2}, respectively. Compared with population density in villages of Java (usually hundreds of persons km^{-2}), these numbers are low. Compared to East Kalimantan as a whole, according to the population census in 1990, 8.88 person/km^{2} (BPS Propinsi Kalimantan Timur, 1998), they were high.

Table 2.2. Population dynamics in the villages of Semoi II and Semoi III during the last two decades. HH=households, pop=population. Source: Departemen Transmigrasi, 1997; Monografi Desa Semoi II, 1998 and Monografi Desa Semoi III, 2000

Times	No. HH		No.Inhabitant (persons)		Pop.density (person km^{-2})	
	Semoi II	Semoi III	Semoi II	Semoi III	Semoi II	Semoi III
- At the foundation of the village (Semoi II, 1978 and Semoi III, 1982)	500	384	2263	1518	37.7	38.0
- Recently (Semoi II, 1998 and Semoi III, 2000)	580	320	2246	1202	37.4	30.0
- Changed	+80	-64	-17	-316	-0.3	-8.0

Village infrastructure, mainly roads, in the Semoi II and Semoi III areas were not in a good condition. The roads were rocky and had many potholes. Therefore, the transportation from and to the villages was irregular and time-consuming. It needed around one hour by a four- wheel drive vehicle to reach these villages from the Wanariset I Research Station, 22 to 27 km away. Public transportation from these villages to the main road of Balikpapan - Samarinda was only available in the morning and the return in the afternoon.

2.4. AGROFORESTRY ESTABLISHMENT AND FARMERS' PREFERENCE OF TREE SPECIES

2.4.1. Justification

The base line survey in Semoi II and Semoi III provided an overview of the real condition of the villages, both biophysically and socio-economically. Abandoned alang-alang grasslands in the areas, illegal cutting and forest encroachments made these sites into excellent objects of research in matters of converting *I. cylindrica* (alang-alang) grassland into more productive land use. The main problem to be solved is how to turn the community back to their agricultural land (in this case *lahan usaha II*) and provide them with competitive on-farm income when compared with income from forest activities. The minimum return to labor will have to be in the order of Rp.15,000 to 20,000,- /day (US$1~Rp.8,000 in 1999 to 2001). Thousands of hectares of alang-alang lands are a large potential resource if they can be converted and developed into productive areas. Solutions must be found to break open the blocked phase of alang-alang ecosystem (Oldeman, 1983; 1990) and establish the diverse, sustainable and profitable land use.

As explained earlier, alang-alang grass is very difficult to eradicate, due to its proliferation by abundant airborne seeds and vigorous rhizomes (par.1.2). In addition, the soil under alang-alang grass is generally poor and has a very low nutrient content. Agroforestry systems that combine perennial tree species and annual cash crops were claimed to solve low production and land degradation (King, 1978). In this case, deep-rooted woody plants should be used to occupy root zones beyond the alang-alang with rhizomes, and which later cast sufficient shade to reduce and eventually eliminate the above ground parts of the light-demanding grass. Beside direct treatments of the grass, other efforts have to be made to improve soil fertility and to prevent recovery of the grass as an initial treatment. This is done by means of planting a legume cover crop.

2.4.2. Tree Species Selection

Tree species selected to be planted on the degraded lands should have the temperament and capability to grow on degraded land; they should be light-demanding, fast-growing, nitrogen-fixing and drought-tolerant species, in a word having pioneer properties. Moreover, they should play a role as components of the agroforestry system as a whole, for soil fertility improvement, as an erosion buffer, and as a multipurpose species.

In order to decide which tree species would be used in this study, both tree characteristics and farmers' preferences were taken into account. Farmers' preference has been assessed during the base line survey, either by means of interviews or by PRA methods. The results showed that farmers preferred such timber species as *Tectona grandis* (teak), *Swietenia macrophylla* (mahogany) and *Peronema canescens* (sungkai), and as multipurpose tree species *Durio zibethinus* (durian), *Aleurites moluccana* (candle nut) and *Artocarpus altilis* (sukun). Based on the tree characters and requirements, finally it was decided mahogany and sungkai (timber trees); candle nut and sukun (multipurpose tree species) to use in the degraded alang-alang grasslands.

2.4.3. Site Selection

Site quality is very complex. It is determined not only by soil fertility but also by site history, topography, current vegetation including whole biological communities (plants, animal and micro-organisms). In forestry, it usually is calibrated by the parameter of height growth of a tree species per year in a certain stand and called traditionally *Bonität* or in English "production class" of a site.

Site selection determines the location of the experimental plots. In the present study, site selection was mainly based on current vegetation, topography, nutrient contents especially phosphorus and mycorrhizal fungi in the soil. Besides, the accessibility to the road as well as permission and co-operation of the land owner were also important. An exploration of the sites was done throughout the areas in the Semoi II and Semoi III villages. As the subject of this study was the conversion of *I. cylindrica* grassland, the selected sites had to be occupied by this grass as dominant current vegetation and they should lie on a similar topography. Therefore, the selected sites were mainly differentiated by soil fertility, particularly as to available and total phosphorus content, and presence of mycorrhizal fungi.

Five sites were selected for the study and three were confirmed by a final assessment, two being discarded. All three sites were occupied by *I. cylindrica* and showed a similar topography, i.e. rolling to hilly. The site characteristics, mainly nutrient content, number of species and the presence of spores of mycorrhizal fungi according to the preliminary survey (site exploration) are presented in Table 2.3. Soil samples were analysed to determine the nutrient content by the Centre for Soil and Agroclimate Research, while the analysis of soil samples to determine the presence of mycorrhizal fungi (species and populations) was carried out by the Forest Biotechnology Laboratory, Inter University Centre of Biotechnology, Bogor Agricultural University.

Table 2.3. Site characteristics, nutrient content and presence of mycorrhizal fungi in the three selected sites, according to the analyses by the Centre for Soil and Agroclimate Research and the Forest Biotechnology Laboratory in Bogor

Sites and position	Nutrient content			Mycorrhizal fungi existing	
	Soil pH (H_2O)	$P_{available}$ (mg kg^{-1}, Olsen P_2O_5)	P_{total} (%)	Number of species	Number of spores
Supandi top	4.2	23.8	0.01	3	38
Supandi slope	4.4	14.7	0.01	4	25
Supandi valley	4.7	14.1	0.02	4	29
Average	4.43	17.53	0.013	4	30
Dasan, top	4.2	10.1	0.01	3	11
Dasan slope	4.1	14.0	0.01	2	13
Dasan valley	5.1	11.4	0.01	3	27
Average	4.47	11.83	0.01	3	17
Muji top	4.4	5.1	0.01	1	8
Muji slope	4.3	10.2	0.02	4	36
Muji valley	4.7	13.1	0.02	3	28
Average	4.47	9.47	0.017	3	24

Table 2.3 shows that the research sites varied in the content of phosphorus, both $P_{available}$ and P_{total}. Presence of mycorrhizal fungi (number of species and spores) also differed among the sites. Further, the site of Supandi (top, slope and valley) became the first block of the main research, which is referred to the experiment designed by the researcher; the site of Dasan became the second block and the site of Muji became the third block.

2.5. CONDITION OF EXPERIMENTAL PLOTS

2.5.1. Location and Layout

Field plots were established on farmer lands in the Semoi II and Semoi III villages. There were two steps in the field experiment. The first step, “main research”, was an experiment designed by the researcher and the next step, “development research”, was an experiment designed by farmers. The main research was managed by the researcher, with paid labour, and the development research was managed by the participating farmers, with some of the inputs provided by the researcher.

The main research

The main research consisted of three blocks, according to the experimental design (see par.3.2.2). The first and second blocks were located in Semoi II, at km 20 (left side) and km 22 (right side) of the road from Wanariset Research Station (Samboja) to Semoi/Sepaku, while the third block was implemented in the village of Semoi III , at km 27 (right side) of the same road (see Fig.2.1). The lands, all *Lahan Usaha II*, were borrowed from the owners by means of an agreement letter between each owner and the researcher. The letter was approved by the village heads as well as by the head of the Wanariset I Research Station as the institution hosting the researcher during the research period. The letters of agreement covered the rights and responsibility of the owners and the researcher during the research period. This on-farm experiment was managed by the researcher, with limited participation of the owner.

The position (co-ordinates) of the research areas is shown in Table 2.4, while the contour map and layout of the research sites presented on Figure 2.2.

Table 2.4. Position of the field plots of the main research set up in the Semoi II and Semoi III villages, East Kalimantan, Indonesia. S=South, E=East, asl=above sea level

Position (coordinates)	First Block	Second Block	Third Block
Latitude	00º 56' 31.354" S	00º 56' 13.644" S	00º 54' 37.722" S
Longitude	116º 54' 01.592" E	116º 54' 15.284" E	116º 52' 49.616" E
Altitude	70 m asl	62 m asl	40 m asl

Figure 2.2. shows the situation, contours layout and organization of the plots of the main research. The three blocks lay on sloping areas. The first and second blocks on a rolling relief with slopes from 3 to 25%, except in a small part of the second block where the slopes up to 55%, facing East, and third block on a hilly relief, with slopes in between 8 and 55%, facing South. Each block is divided in two main plots and each main plot in 12 sub-plots (for details see chapter 3). These sketched attributes already show that the plots are not ecologically identical, representing similar but distinct site qualities.

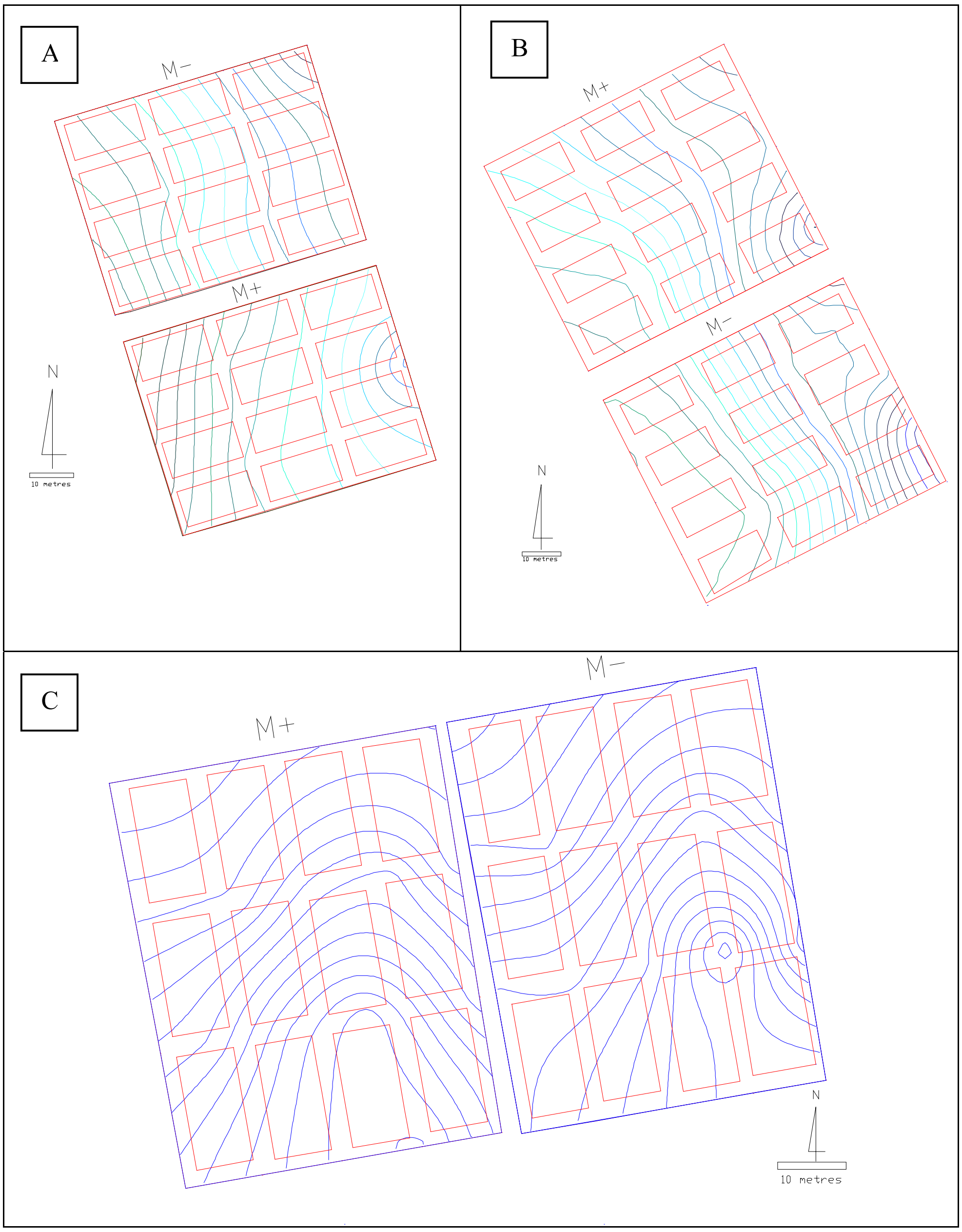


Fig.2.2. Contour map and layout of the experimental plots. A. First block, B. Second block, C. Third block

Therefore, the three blocks are not simply replications, but represent three levels of one factor "site quality". However, from a statistical analysis, these blocks can act, and some times be replications as they are used to test hypotheses about 'generic' attributes of the different treatments tested (Gomez and Gomez, 1984; Steel and Torrie, 1991). Due to the heterogeneity among the sites (blocks), the design of the experiment used was a Split Plot in a random block design.

The development research

The development research was conducted at five places (blocks), three in the Semoi II and two in the Semoi III village. The experiment involved five participant farmers, owners of the respective plots, namely Sarjuni, Mustarkun and Sumardi in the Semoi II; A. Madjid and Kadir in the Semoi III. Each block was located close to its owner's house, and occupied the land of the *Lahan Usaha I.*

2.5.2. Vegetation

The main research

As in the whole area of the villages, the initial vegetation at the three experimental blocks of the main research was dominated by *Imperata cylindrica* (alang-alang) grass. However, there are differences among the blocks. First block was occupied by alang-alang of 1 to 1.5 m high, mixed with several weeds, such as *Chromolaena odorata* (Compositae) and *Melastoma malabathrica* (Melastomaceae). Second block was dominated by alang-alang of around 0.75 m height. This grassland was burnt 3 months before the start of the experiment. Other vegetation in this plot was composed by rather frequent ferns (*Pteridium aquilinum,* Hypolepidaceae), *Melastoma malabathrica* (Melastomaceae) and *Chromolaena odorata* (Compositae). Third block was fully covered by alang-alang of 1.5 to 2 m high without any other species except in a small part of the valley, where *Mikania* sp. occurred.

The composition of the plant community and distribution of dead wood in the area showed that the previous vegetation of first and third blocks was dominated by "Ulin" or iron wood (*Eusideroxylon zwageri*), while second block was dominated by Bangkirai (*Shorea laevis*). Plate 2.3 shows the initial condition of the vegetation in these three blocks.

The development research

The initial vegetation in the five blocks of the experiment designed by farmers was also dominated by alang-alang grass. However, in two blocks namely at Sarjuni and Sumardi farms' the grass was mixed with weeds such as *Melastoma malabathrica*, *Pteridium aquilinum*, *Mikania* sp. etc.

2.5.3. Precipitation

The precipitation was measured in each plot of the main research from the time the plots were established until the end of the research period. A rain gauge was placed in each plot and the amount of precipitation was recorded immediately every time a rainy period was over, except when it rained at night. The monthly precipitation in the research sites during the research period is presented in Fig. 2.3.

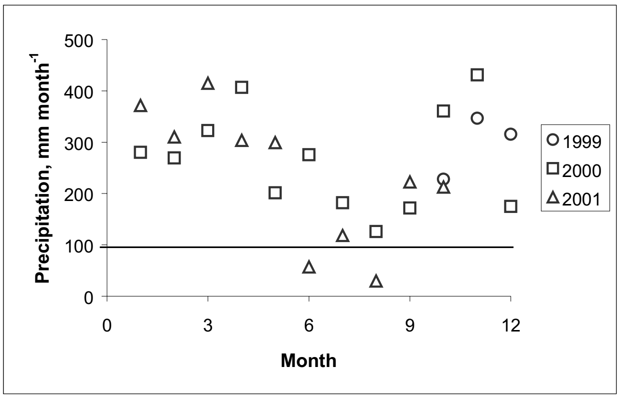


Fig. 2.3. Monthly precipitation (mm month^{-1}) in the research sites from October 1999 to September 2001.

Fig. 2.3 shows the fluctuation of the precipitation, which declined around June, July and August. However, December 2000 had little rain and there were strong winds. The total rainfall from October 1999 to September 2000 was 3126 mm and from October 2000 to September 2001 was 3096.

2.5.4. Soil Properties

The main research

The initial soil properties in the three blocks of the experiment were surveyed, including a soil profile description, soil sample collection and analysis. The soil description made was based on the position of the plots (upper, middle and lower slope), the slope classification (flat, sloping, steep, very steep), soil texture of upper layer, soil drainage (slow, moderate, fast), and effective soil depth (shallow, deep and very deep) (Touber et. al., 1989; FAO, 1977; Balsem et. al., 1989). Soil drainage and effective soil depth were assessed by means of a soil auger with intervals of 20 m and to a depth of 1.25 m. Soil map units were drawn according to the field description of the soils.

Based on the above fieldwork, the soil type in the block I is an *Ultisol* (*udults*), from the family of *Typic Hapludults*. In block II it is also an *Ultisol*, from the family of

Typic Paleudults, and in the block III it is an *Inceptisol* (*dystropepts*) from the family of *Typic Dystropepts*. An *Ultisol* is a soil type found in the zone of high humidity. It includes advanced stages of soil development with clear accumulations of clay at the B horizon, so it formed an *argilic* Bt horizon. The soil acidity (pH H_2O) ranged from 4 to 5. An *Inceptisol* is a developing soil type, which is highly affected by the parent material and climate.

Soil map units were drawn for each block of the research site. The first block consisted of four soil units, namely USl 234, MSl 233, LSl 233 and LM 223 (see Fig. 2.4). The soil unit USl 234 is a *Typic hapludult* with rather coarse textures, ranging from sandy loam to sandy clay loam. The soil unit is found at the upper parts, with a gentle slope from 3 to 16% with an effective soil depth of more than 1.20 m. The soil drainage was rather fast, with little or no "mottling" at 1.0 m depth. The soil unit MSl 233 is dominated by *Typic hapludults*, with rather coarse textures, ranging from sandy loam to sandy clay loam. This soil unit lies in the middle of a gentle slope from 8 to 16%, has an effective soil depth between 0.82 and 1.20 m and soil drainage was moderate. The LSl 233 soil unit belongs to the *Typic hapludults* and is found at the foot of gentle slopes from 8 to 16%. The soil texture was sandy clay loam, soil drainage was moderate and effective soil depth ranges between 0.82 and 1.20 m. The LM 223 is a soil unit on rather steep slopes from 16 to 25%, it contains sandy clay loam, soil drainage is moderate and it lies in the lower reaches of the first block.

The second block is covered by four soil units i.e. USl 233, MM 233, MSl 443 and LSt 222 (Fig. 2.4). The USl 233 is a soil unit of a *Typic paleudult* with coarse textures, ranging from sandy loam to sandy clay loam. It spreads at the upper parts, with a gentle slope from 3 to16%. It has an effective soil depth between 0.82 and 1.20 m and soil drainage was moderate. MM 233 is a soil unit with fine textures, ranging from sandy clay loam to silty clay loam. It spreads at the middle parts with rather steep slopes, ranging from 16 to 25%. It was a deep soil, has an effective soil depth between 0.82 and 1.20 m, the soil drainage was moderate. The MSl 443 is a soil unit found in the middle parts of a gentle slope from 8 to 16%. It contains coarse textures of sandy loam, has an effective soil depth between 0.51 to 0.80 m, the soil drainage was rather fast. The LSt 222 is a soil unit, it lies in the lower parts of the second block with steep slopes from 25 to 55%. The soil textures ranged between sandy clay loam and silty clay loam, it has an effective soil depth between 0.51 and 0.80 m and the soil drainage was rather slow.

The third block also consisted of four soil units, USt 132, MSt 122, LSt 221 and LSt 243 (Fig.2.4). The soil unit USt 132 lies at the upper parts with steep slopes from 8 to 55%. Its soil textures ranging from sandy clay to clay loam, has an effective soil depth between 0.51 to 0.80 m and the soil drainage was moderate. The MSt 122 is found at the middle parts with steep slopes from 25 to 55%. The effective soil depth was between 51 and 80 cm and the soil texture was sandy clay. The LSt 221 lies at the lower parts with steep slopes from 25 to 55%.

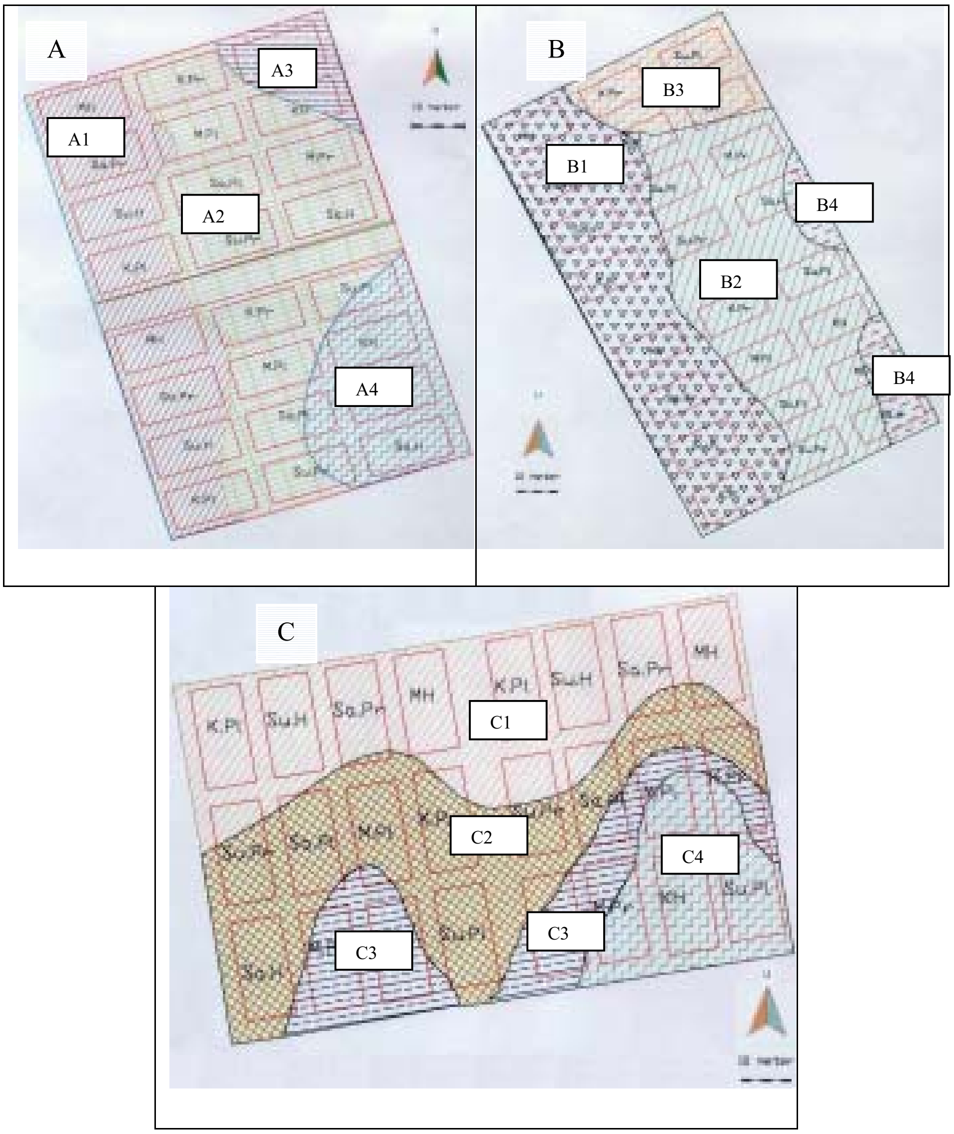


Fig. 2.4. Soil map units of the three blocks of the main research according to the position of the plots, slope, soil texture, soil drainage and effective soil depth. It was overlaid on the plot layout. A is the first plot, B is the second plot and C is the third plot. A1=USl 234, A2=MSl 233, A3=LM 223, A4=LSl 233. B1=USl 233, B2=MM 233, B3=MSl 443, B4=LSt 222. C1=UST 132, C2=MSt 122, C3=LSt 221, C4=LSt 243.

The soil texture was clay loam, and the soil drainage was rather slow, has a rather shallow effective soil depth, between 0.26 to 0.50 m with many sand-stones and rusty. The soil unit LSt 243 is similar to the LSt 221 except for the soil depth and soil drainage. This soil unit has an effective soil depth of between 0.82 and 0.120 m and the soil drainage was rather fast.

A soil profile was made in each block of the main research. The position of the profile was determined by the distribution of dominant soil types over each block. The depth of the soil profiles was 1.80 m. The following paragraphs describe the soil profiles in the three blocks, as shown by Plate 2.4.

Block I

Topography : Rolling
Slope : 15 %
Position : Middle slope, east to west
Parent material : Clay stone
Water table : > 1.80 m
Vegetation/land use : *Imperata cylindrica* (alang-alang) grass
Soil classification : *Typic hapludults* (USDA)
Diagnostic horizon : *Argilic* horizon
Stoniness (%) : none
Rock out crop (%) : none
Flooding frequency : none
Effective soil depth (cm) : 1.35 m
Soil drainage : moderately well drained

Horizon	Depth (cm)	Description
Ao	0-8	Dark yellow brown (10 YR 3/1), exterior large peds, moist; silt loam; fine, sub angular blocky; loose (moist), slightly sticky non plastic (wet); many fine to medium and common coarse pores; many fine, and few medium to coarse roots throughout horizon; clear and wavy boundary to
E	8-16	Reddish yellow (7.5 YR 6/8), interior large peds, moist; clay loam; medium angular blocky, slightly firm (moist), sticky and non plastic (wet); many coarse distinct irregular reduction (10 YR 7/1) mottles; common fine to medium and many coarse pores; few fine to medium and coarse roots throughout horizon; clear, wavy boundary to

Horizon	Depth (cm)	Description
Bt1	16-52	Yellowish brown (10 YR 5/6), interior large peds, moist; clay; medium angular blocky; firm (moist); very sticky and plastic (wet); few fine to medium and many coarse pores; few, fine to medium and coarse roots throughout horizon; many discontinuous clay films on ped faces; clear, gradual boundary to
BC	52-93	Yellowish brown (10 YR 5/8), interior large peds, moist;clay; medium angular blocky; firm (moist), very sticky and plastic (wet); common fine distinct irregular reduction mottles (2.5 Y 7/2), interspersed in the matrix; few fine to medium and many coarse pores; few fine medium and many coarse root throughout horizon; smooth and gradual boundary to
C	93-180	Strong brown (7.5 YR 5/8), interior large peds, moist; clay clay;coarse angular blocky; firm (moist), very sticky and plastic (wet); few common fine irregular reduction (5Y 7/4) mottles, interspersed in the matrix; few fine to medium and coarse pores; few fine to medium and coarse roots throughout horizon; boundary not reached

Block II

Topography : Rolling
Slope : 15 %
Position : Middle slope (east to west)
Parent material : Clay stone
Water table : > 1.80 m
Vegetation : *Imperata cylindrica* (alang-alang) grass
Soil classification : *Typic paleudults* (USDA)
Diagnostic Horizon : *Argilic* horizon
Stoniness (%) : (none)
Rock Out crop (%) : (none)
Flooding Frequency : (none)
Effective soil depth (cm) : 1.35 m
Soil drainage : moderately well drained

Horizon	Depth (cm)	Description
Ah	0 – 13	Dark yellowish brown (10 YR 4/2), exterior large peds faces, moist; silt loam; fine sub angular blocky; freeable (moist), slightly sticky and non plastic (wet); many fine to medium and few coarse pores; many fine, common medium and few coarse roots throughout horizon; clear, smooth boundary to
E	13 – 35	Brownish yellow (10 YR 6/8), interior large peds faces, moist; loam; medium sub angular blocky; slightly firm (moist), sticky non plastic (wet); many medium distinct irregular reduction (10 YR 6/1) mottles, interspersed in the matrix; common fine to medium and many coarse pores; few fine to coarse roots throughout horizon; clear, wavy boundary to
Bt1	35 – 70	Yellowish brown (10 YR 5/8), interior large peds faces, moist; clay loam; coarse angular blocky, firm (moist), sticky and slightly plastic (wet) ; fine distinct rounded reduction (10 YR 6/2) mottles, interspersed in the matrix; many continuous clay films on ped faces; few fine to coarse pores; few fine to coarse roots, throughout horizon; diffuse, wavy boundary to
Bt2	70 – 118	Brownish yellow (10 YR 6/8), interior large peds faces, moist; clay; coarse angular blocky; firm (moist), strong sticky and plastic (wet) ; few fine to coarse pores; many continuous clay films on ped faces; few fine to coarse roots throughout horizon; diffuse, wavy boundary to
BC	118 – 180	Yellowish brown (10 YR 5/6), interior large peds faces, moist; clay; coarse angular blocky; firm (moist), very sticky and plastic (wet); many fine distinct rounded oxidation (10 YR 7/8) mottles, interspersed in the matrix; many fine distinct hard (10 YR 5/8) concretions; few fine to coarse pores; few fine to coarse roots throughout horizon; boundary not reached

Block III

Topography	: Hilly
Slope	: 20 %
Position	: Middle slope (north to south)
Parent material	: Clay stone
Water table	: > 1.80 m
Vegetation	: *Imperata cylindrica* (alang-alang) grass
Soil classification	: *Typic Dystropepts* (USDA)

Diagnostic horizon : *Cambic* horizon
Stoniness (%) : 60 %
Rock Out crop (%) : none
Flooding frequency : none
Effective soil depth (cm) : 0.85 m
Soil drainage : moderately well drained

Horizon	Depth (cm)	Description
Ah	0 – 4	Dark yellowish brown (10 YR 4/2), interior peds faces, moist; silt loam; fine sub angular blocky; freeable (moist), slightly sticky and non plastic (wet); many fine to medium, and few coarse pores; many and few medium and coarse roots, throughout the horizon; clear, smooth boundary to
Bw	4 – 84	Yellowish red (5 YR 5/8), interior large peds faces, moist; clay; coarse angular blocky; firm (moist), very sticky and plastic (wet); common fine rounded silica concretion; few fine to coarse pores; few fine to coarse roots throughout horizon
BwC	84 – 165	Yellowish red (5 YR 5/8), interior large peds faces, moist; clay; coarse angular blocky; firm (moist), very sticky and plastic (wet); many coarse rounded 10 YR 4/8 (red) sand stone, few fine to coarse pores; few fine to coarse roots throughout horizon; boundary not reached

Soil samples were collected to determine the soil chemical and physical properties. For determining chemical properties, composite soil samples were collected according to the soil units. Undisturbed soil samples were collected to determine the physical soil properties. Two layers of soil depth were sampled, over a depth of 0 to 20 cm and 20 to 40 cm at each soil profile. Soil samples for chemical properties were analyzed by the Centre for Tropical Forest Research, Mulawarman University, while physical properties were determined by the Soil Laboratory, Faculty of Forestry, Mulawarman University. The chemical and physical soil properties of the three blocks of the research sites are presented in Table 2.5 and Table 2.6.

Table 2.5. Average chemical soil properties and textures of three blocks of the main research, according to the analysis by the Centre for Tropical Forest Research, Mulawarman University, in 1999. SCL=sandy clay loam, SL=sandy loam, SC=sandy clay, CL=clay loam

Blocks/soil map units	Chemical soil properties								Tex-ture
	PH (H_20)	N (%)	P (mg kg^{-1})	K ($cmol_e$ kg^{-1})	$C_{organic}$ (%)	Mg ($cmol_e$ kg^{-1})	CEC ($cmol_e$ kg^{-1})	Al ($cmol_e$ kg^{-1})	
I: USl 234	4.9	0.04	12.3	0.28	1.4	0.16	12.1	5.1	SCL
MSl 233	4.9	0.07	7.2	0.21	1.2	0.13	9.9	5.1	SCL
LSl 233	4.6	0.10	11.2	0.24	1.5	0.18	11.8	5.6	SCL
LM 223	5.3	0.08	9.0	0.25	1.5	0.16	10.1	4.3	SCL
Average	**4.9**	**0.07**	**9.9**	**0.25**	**1.4**	**0.16**	**11.0**	**5.0**	-
II: Usl 233	5.1	0.06	10.1	0.16	1.5	0.10	8.1	4.0	SCL
MM 233	5.2	0.09	6.6	0.21	1.6	0.19	10.6	3.0	SCL
MSl 443	5.3	0.05	8.6	0.19	1.3	0.12	7.0	2.3	SL
LSt 222	5.1	0.05	4.1	0.20	1.4	0.10	7.8	3.2	SCL
Average	**5.2**	**0.06**	**7.4**	**0.19**	**1.5**	**0.13**	**8.4**	**3.1**	-
III:USt 132	5.3	0.08	3.9	0.24	1.6	0.19	16.3	6.5	SC
MSt 122	5.2	0.10	4.2	0.31	1.7	0.26	16.9	5.5	SC
LSt 221	5.5	0.08	5.4	0.26	1.5	0.21	17.1	4.7	CL
LSt 243	5.4	0.11	4.0	0.28	1.7	0.26	18.3	4.9	CL
Average	**5.4**	**0.09**	**4.4**	**0.27**	**1.6**	**0.23**	**17.2**	**5.4**	-

Table 2.6. Physical soil properties of three blocks of the main research, according to analysis by the Soil Laboratory, Faculty of Forestry, Mulawarman University

Blocks/soil profiles/soil layers	Bulk density	Porosity (total)	Field capacity (vol.%)	Water hold. capacity (vol.%)
I: 0 – 20	1.2	54.70	50.16	41.28
20 – 40	1.3	50.91	41.26	32.68
II: 0 – 20	1.1	58.50	36.19	27.08
20 – 40	1.5	43.40	33.75	23.24
III: 0 – 20	1.3	50.90	41.60	30.29
20 – 40	1.4	47.20	39.76	28.14

It can be concluded that the status of the soil fertility in the areas, according to PPT (1997), was very low to low (Table 2.5). Block II had the lowest nitrogen (N), potassium (K) and magnesium (Mg) contents as well as cation exchange capacity (CEC). Block II also was the driest of the three (Table 2.6) at both depth levels.

The development research

Several composite soil samples at the five blocks of the experiment designed by farmers were collected and analyzed for the chemical properties and texture at the Biotrop Soil Laboratory. The results are presented in Table 2.7.

Table 2.7. Chemical soil properties and texture of the five blocks of the experiments design by the farmers

Bloks/ Farmers	Chemical soil properties								Texture		
	pH ($H_2 0$)	N (%)	$P_{available}$ (mg kg^{-1}) Bray I	K ($cmol_e$ kg^{-1})	$C_{org.}$ (%)	Mg ($cmol_e$ kg^{-1})	CEC ($cmol_e$ kg^{-1})	Al ($cmol_e$ kg^{-1})	Sand	Silt	Clay
I.Sarjuni	4.9	0.07	11.54	0.14	0.64	0.83	9.83	1.52	76.8	8.6	14.6
II.Mustarkun	4.6	0.11	9.04	0.19	1.08	1.31	11.41	2.47	12.5	47.7	39.8
III.Sumardi	4.5	0.09	6.23	0.13	0.77	0.86	10.28	2.18	65.8	17.9	16.3
IV.A.Madjid	4.6	0.09	8.37	0.23	0.86	1.27	13.29	3.14	3.2	49.2	47.6
V.Kadir	4.5	0.12	6.85	0.27	1.43	1.04	14.37	2.76	2.7	43.5	53.8

2.5.5. The Clusters of Experimental Plots

Due to the heterogeneity of the experimental plots, both the three blocks of the main research and the five blocks of development research, the blocks were clustered. Criteria for clustering were site characteristics such as slope or topography, vegetation, water holding capacity, soil depth, soil texture, nutrient availability. The site characteristics were score from 1(high), 2 (moderate), 3 (low), while the site qualities were ranked from 1 (rich), 2 (moderate), 3 (poor) and 4 (very poor) as described in Table 2.8 and Table 2.9.

Table 2.8. Scoring of site characteristics

No.	Items	Characteristics and score		
		1	2	3
1	Precipitation	High (.> 2500mm)	Moderate(1500 to 2500)	Low (< 1500)
2	Topography	Flat	Rolling	Hilly
3	Water holding capacity	High (> 40 vol. %)	Moderate (30 to 40)	Low (< 30)
4	(Water) field capacity	High (> 50 vol.%)	Moderate (40 to 50)	Low (< 40 %)
5	Soil depth	Deep (> 100 cm)	Medium (75 to 100)	Shallow (<75)
6	Nutrients:			
	- CEC (cation exchange capacity)	High (>15 $\text{cmol}_e\,\text{kg}^{-1}$)	Moderate (10 to 15)	Low (< 10)
	- Nitrogen (N)	High (> 0.10 %)	Moderate (0.05 to 0.10)	Low (<0.05)
	- Phosphorus ($P_{available}$)	High (>10 $\text{cmol}_e\,\text{kg}^{-1}$)	Moderate (5 to 10)	Low (< 5)
	- Potassium (K)	High (>30 $\text{cmol}_e\,\text{kg}^{-1}$)	Moderate (20 to 30)	Low (< 20)
	- Magnesium (Mg)	High (>20 $\text{cmol}_e\,\text{kg}^{-1}$)	Moderate (10 to 20)	Low (< 10)
	- $C_{organic}$	High (> 1.5%)	Moderate (1 to 1.5)	Low (< 1)
7	Soil Texture	Sandy clay loam and Silty clay loam	Sandy clay and Silty clay	Clay and Sandy loam
8	Soil pH	High (>6)	Moderate (5-6)	Low (<5)
9	Presence of mycorrhizal fungi (average in 50 g soil sample)			
	- number of species	High (> 3)	Moderate (2-3)	Low (<2)
	- number of spores	High (> 30)	Moderate (20-30)	Low (<20)
10	Other vegetation:			
	- ferns	Rare	Some	Frequent
	- Melastoma	Rare	Some	Frequent

Based on the classification of sites characteristics presented in Table 2.8, the experimental plot qualities were clustered as follows (Table 2.9).

Table 2.9. The experimental plots clustered according to the sites characteristics.
na=no data available, adjusted as moderate level

No.	Items	Main research (Blocks)			Development research (Blocks)				
		I	II	III	I	II	III	IV	V
1	Precipitation	1	1	1	1	1	1	1	1
2	Topography	2	2	3	1	2	1	2	2
3	Water holding capacity	1	3	2	na	na	na	na	na
4	(Water) field capacity	1	3	2	na	na	na	na	na
5	Soil depth	1	1	2	na	na	na	na	na
6	Nutrients:								
	- CEC (cation exchange capacity)	2	3	1	3	2	2	2	2
	- Nitrogen (N)	2	2	2	2	1	2	2	1
	- Phosphorus ($P_{available}$)	2	2	3	1	2	2	2	2
	- Potassium (K)	2	3	2	1	1	1	2	2
	- Magnesium (Mg)	2	2	1	2	1	2	1	1
	- $C_{organic}$	2	2	1	1	2	1	1	2
7	Soil Texture	1	1	2	3	1	3	2	2
8	Soil pH	3	2	2	3	3	3	3	3
9	Presence of mycorrhizal fungi (average in 50 g soil sample)								
	- number of species	1	2	2	na	na	na	na	na
	- number of spores	1	3	2	na	na	na	na	na
10	Other vegetation:								
	- ferns	2	3	1	2	1	3	1	1
	- melastoma	2	3	1	3	1	3	1	1
11	Adjusted for no data available (na)				10	10	10	10	10
	Total score	28	38	30	33	28	34	30	30
	Site quality of the blocks	1	3	2	3	1	4	2	2

According to the plot classification in Table 2.9, it was concluded that the first block of the experimental plot of the main research was most hospitable to plant growth (1, rich), followed by the third block (2, moderate) and finally was the second block (3, poor).

Whereas for the development research, the most hospitable to plant growth was the second block (1, rich), followed by the fourth and fifth blocks (2, moderate), the first block (3, poor) and finally the third block (4, very poor).

3. MYCORRHIZAL TREATMENT AND TREE GROWTH ON DEGRADED *Imperata cylindrica* GRASSLAND

3.1. INTRODUCTION

The role of mycorrhizae in plant growth has been demonstrated by many authors (Valdens and Grada-Yautentzi, 1980; Whittingham and Read, 1982; Harley and Smith, 1983; Schenck, 1985; Smits, 1994; Yasman, 1995; Prematuri, 1995; Setiadi, 1996; Prematuri and Dodd, 1997; Smith and Read, 1997; Omon, 2002). Much of the research thus far was accomplished in the laboratory, greenhouse or in the natural forest. However, field research testing inoculum of mycorrhizal fungi to stimulate tree growth in tree plantations is still scarce. Almost all plant species of economic importance in the tropics are, under normal conditions associated (infected) with mycorrhizal fungi; most of them associate with arbuscular mycorrhizae (also known as vesicular-arbuscular or VA mycorrhizae) and some tree species associate with ectomycorrhizae (Gerdemann, 1975; Harley, 1969; Smith and Read, 1997). On specific biologically impoverished sites such as mine spoils, several isolates of VA mycorrhizal fungi proved to promote growth of fast-growing and nitrogen- fixing plants (Prematuri, 1995; Setiadi, 1996; Prematuri and Dodd, 1997). The ability of these mycorrhizal fungi in accelerating tree growth on alang-alang grassland remains to be tested. The *Imperata cylindrica* (alang-alang) grasslands are generally poor in nutrients and thus can be called 'degraded', but they are not necessarily poor from a soil biological prespective and may contain high densities of mycorrhizal spores (Setiadi, 1999).

A considerable amount of research on *I. cylindrica* control methods was done during the last decades. Glyphosate is a systemic herbicide, which may be effective in controlling the grass and is widely used by most managers of estate crops and relative rich farmers (Purnomosidhi et al., in press.). However, small-holder farmers have serious financial constraints to implement the high cost of this alang-alang control method, since the herbicide is expensive. A physical control method commonly used by small farmers is digging the land by a hoe and expose the grass rhizome to the sun. This method may be effective when a significant dry season occurs and the rhizome can be killed; if it rains early, however, the rhizome will readily resprout and little control is achieved. Another serious problem of this method is that it is labour consuming; one person can only dig up 150 to 200 m^2 a day (Purnomosidhi et al., in press). Simply slashing the grass takes less labour, but the grass will sprout back quickly from the reserves in the rhizomes, so slashing must be repeated frequently to achieve optimal control. A method that has recently received attention is pressing the grass (NRI et al., 1996; Friday et al., 1999). In this method the grass is pressed low onto ground by trampling or by rolling a weight over it. Pressing bends the base of an alang-alang culm (stem) like folding a plastic water hose. The weight of the grass helps to keep it bent down, so grasses in the lower layer die. Friday et al. (1999), reported that the pressing method has several advantages. The rate of grass regrowth after pressing is only 20 to 60% of that after slashing, so pressing does not have to be repeated as often as slashing. Pressing is easier than slashing. One strong, experienced person can press about 900 m^2 a day.

Women and children can press alang-alang as well. It can also be done selectively around existing trees or to prepare space for trees to be planted.

Since each of these *I. cylindrica* control methods has limitations and they have not been systematically compared in the context of smallholder tree planting, a test was initiated on how these methods can be integrated into shade-based control by means of tree and legume cover crop planting. The shade of the trees and the legume cover crop is expected to prevent recovery of the grass after the treatment as well as to contribute to soil fertility improvement.

In this study, three methods of alang-alang control were tested i.e. spraying the grass with a herbicide (Glyphosate), ploughing or hoeing the land, and pressing the grass with a heavy log. Each method was integrated with planting of deep-rooted woody plants and a legume cover crop to crowd the grass out, both above and under ground.

The shading capacity of trees is different among species. It depends on the branching pattern and crown architecture of the trees (Hallé et al., 1978; Oldeman, 1990; Vester, 1997). Specifically, it depended on both the total leaf areas and the spatial distribution of leaves. Light interception per unit leaf area is related to the thickness of the leaves. The ability of tree species to produce shade rapidly is accelerated by fast vegetative growth. Application of mycorrhizal inoculum was expected to stimulate vegetative tree growth. The latter variable can be numerically expressed by relative shading, leaf area index (LAI), and crown area index of each tree species.

As described in chapter 2, tree species selection was based on the properties of species, in particular a pioneer temperament, and the role in the agroforestry system as a whole as well as preferences of the local farmers. The tree species selected were Mahogany (*Swietenia macrophylla* King, Meliaceae); Sungkai (*Peronema canescens* Jack., Verbenaceae); Candle nut (*Aleurites moluccana* (L.) Willd., Euphorbiaceae) and Sukun (*Artocarpus altilis* Fosberg, Moraceae). The first two are timber trees and the latter two are multipurpose tree species, with both fruits and wood as valuable products. *Swietenia macrophylla* is also known as broad-leaved mahogany.

Mahogany is one species included in the Industrial Forest Plantation Program (HTI), aiming to establish man-made forests in Indonesia. Mahogany is a shade tolerant species, it has an ability to grow in alang-alang or shrub environments, and it is especially suited for reforestation on dense alang-alang grassland. The plant can grow in regions with an A or B type precipitation according to the classification of Schmidt and Ferguson (1951). The tree is tolerant to deficiency of oxygen for period up to 70 days, so it can be planted and adapted on sites, which are flooded occasionally (Ditjen Kehutanan, 1980). Alrasjid (1984) reported an annual increment of mahogany of 14 $m^3ha^{-1}year^{-1}$ with a production cycle of 30 years. *S. macrophylla* is a large, deciduous tree with an umbrella-shaped crown (Styles *ex* Pennington, 1981 *ex* Mayhew and Newton, 1988), frequently reaching heights of over 30 m and a diameter at breast height (dbh) of over 1.5 m (Lamb *in* Mayhew and Newton, 1998). Heights of 45 to 60 m and diameters of 2.5 to 3.5 m were not rare before the mahogany populations in natural forest were exterminated by logging (de Irmay *in* Mayhew and Newton, 1998). Mahogany wood has an attractive colour, it is usually used for furniture, play-wood, handicraft and light constructions (Samingan, 1982; Martawijaya et al., 1989). The durability of the wood falls in class III (moderately durable), while the strength of the wood is in class II to III (Martawijaya et al., 1989). Mahogany timber is prized particularly for its colour and workability; it is primarily valued for construction of high-value furniture and interior fittings (Palmer, 1994). The colour and density of the wood vary markedly with geographic origin and growth environment (Lamprecht, 1989).

Sungkai is also a species included in the Indonesian Industrial Forest Plantation Program. Sungkai grows naturally in the western part of Indonesia, Sumatera, Java and Kalimantan Islands, mainly in secondary forests up to 700 m above sea level. The tree is tolerant to drought and fire (Hatta, 1999). The trees frequently reach a height of 22 m and a diameter at breast height of 60 cm. Tree and wood properties are quite similar to teak (*Tectona grandis*), but the wood is lighter and so is the wood colour (Heyne, 1987 and Evans, 1992). Sungkai wood is used for interior construction, furniture, decorative veneer, and handicraft (Kapisa and Sapulete, 1995). Its wood shows class III durability and class II/III strength (Martawijaya et al., 1989). Propagation of Sungkai by means of stem cuttings is widely used right now (Hatta, 1999).

In Indonesia, Candle nut is used through-out the country, being widely cultivated in South Sulawesi, Java, Moluccas and North Sumatera. Candle nut is usually planted by local farmers, but also grows naturally in forestlands. The fruit is used for spices, medicines or as raw material for paints, soups and cosmetics. The species is a multipurpose tree, planted by local inhabitants for the fruits and by the Forestry Department for the woods. Candle nut was also planted widely for the purpose of reforestation. The species can adapt to a wide range of soil types (lime soils, acid soils and sandy soils), in arid as well as humid zones. It grows well at altitudes of 0 to 800 m above sea level (Dali and Ginting, 1993). Ginting and Semadi (1980), reported that candle nut trees grow well in an alang-alang grass environment in Tanjung Bintang, South Lampung where they gradually replaced the grass. The trees usually reach a total height of some 35 m with a free bole of 9 to14 m long, and a diameter at breast height of one meter. The common use of the wood is veneer, packing material, handicraft etc. The wood has a class V durability (Martawijaya et al., 1989).

Sukun or breadfruit is a species of the wet tropics, preferring a hot and humid climate, with a temperature of 20 to 40°C, a precipitation of 2000 to 3000 mm and a relative atmospheric humidity of 70 to 90%. Young trees grow better under shade but later full sun is required. Tree growth is best in deep, well-drained, alluvial soils rich in humus (Rajendran, 1992). In general, breadfruit trees are large, attractive and evergreen, reaching heights of 15 to 20 m. The tree has a smooth, light-coloured bark, and the trunk may be as large as 1.2 m in diameter. The wood has an attractive golden colour, turning darker upon exposure to air (Ragone, 1997). Breadfruit grows best in equatorial lowlands below 650 m; it is occasionally found in the highlands, but yield and fruit quality suffer in cooler conditions (Rajendran, 1992). Breadfruit trees are generally propagated vegetatively from root cuttings or shoots. The roots grow horizontally on or slightly below the surface of the ground and often produce an adventitious shoot, especially if cut or damaged. Breadfruit is a versatile food and can be cooked and eaten at all stages of maturity, although it is most commonly harvested and consumed when mature. The fruit is a nutritious and a valuable staple food in the tropics (Ragone, 1997), where it traditionally functions as a life insurance in case of misharvest of rice (Oldeman, 1988).

The study described in the present chapter addresses the following questions:

1. What is the role of inoculated mycorrhizal fungi in accelerating the growth of four tree species in a young agroforestry system, established on degraded *I. cylindrica* grassland?
2. Have the four tree species selected capabilities to be grown on degraded *I. cylindrica* grasslands, growing vigorously and contributing to the conversion of an alang-alang ecosystem into an agroforestry ecosystem?
3. Are there important differences in effectiveness between three methods of *I. cylindrica* management in establishing trees in the grass environment?

3.2. MATERIAL AND METHODS

The research activities consisted of two phases. The first one was seedling preparation in the nursery and the next one consisted of field experiments.

3.2.1. Seedling Preparation

Seedling preparation was carried out in the Wanariset Nursery, Wanariset I Research Station (Location of the MOF-Tropenbos Kalimantan Programme), East Kalimantan, Indonesia (see paragraph 2.1). All nursery activities were conducted within six months, from April to September 1999. The four tree species (see par. 3.1) were grown in the nursery. Seeds of mahogany were collected from a mature mahogany stand in the INHUTANI I (Forest state enterprise) plantation forest, near Balikpapan. Sungkai stem cuttings were collected from mature sungkai trees surrounding the Wanariset Nursery. Candle nut seeds were obtained from the local inhabitants, who collected the seeds from the mature candle nut trees in their home-gardens, around the Wanariset Station. Whereas root cuttings of sukun were obtained from the Gunung Lampu area, about 20 km to the Northeast of the Wanariset Station.

Mahogany and Candle nut seeds germinated in seedbeds before being planted out in black plastic bags. Sungkai and Sukun were propagated respectively by means of stem and root cuttings, inserted directly in the same type of plastic bag. A mixed medium, consisting of topsoil, cow manure and sand in a ratio of 3:1:1 was used for growing the seedlings. This medium was pasteurised by solar radiation. The purpose of the treatment was to reduce populations of undesirable micro-organisms living in the medium. Solar radiation during the highest temperature in a tropical country, like Indonesia (between 11.00 till 15.00) can raise soil temperatures in open areas up to 45°C. This heat has been proven to kill many and various micro-organisms living in the soil (Smits, 1983; Bowen and Theodorou, 1973; Smits et. al., 1987 and Smits, 1994). It is emphasized that the medium was not completely sterilized (cf. Omon, 2002). After pasteurization, the medium was put into plastic bags sized 10 x 15 cm.

The semi-commercial product, "Mycofer", was used as source of mycorrhizal inoculum to inoculate half of the seedlings in the nursery. It contains spores of four species of vesicular-arbuscular mycorrhizal fungi, i.e. *Glomus manihotis*, *Glomus etunicatum*, *Gigaspora rosea* and *Acaulospora tuberculata*. This inoculum is granular. It was applied by bringing it into the medium, around the root zone, in a dosage of 10 g per bag. The seedlings in the containers were shaded by mesh-nets that shaded out 25% of full sunlight. Hence, the total light intensity that could be captured by the seedling was 75% of full sunlight. Seedlings were watered twice a day, in the morning and in the afternoon. Nursery weeding was carried out manually every month, until the plants were ready to be transplanted to the field, 5 months later.

Seedlings in the nursery were divided into two batches. The first batch was used for nursery research while the second batch was reserved for field experiments.

Nursery experiment

The nursery experiment was set up according to a random block design in a factorial experiment with three blocks or replications. There are two factors:

1. tree species : mahogany **(M)**, sungkai **(Sa)**, and candle nut **(K)**)
2. mycorrhizal fungi treatments : inoculated **(+)** and not inoculated **(-)**

Each of the experimental units consisted of 30 seedling bags. Therefore, there were 3x2x3x30=540 seedling bags. Inoculated and non-inoculated seedlings were placed separately, so cross-infection through seedling media and water could be avoided.

Observation and measurement of the seedling growth covered height and diameter of the seedling stem, dry weight of the total biomass and shoot-root ratio. Height and diameter of the stem were measured three times, at the start, in the middle, and at the end of the nursery phase. The stem height was measured from the root collar to the end of the growing point using a meter stick, while the seedling diameter was measured a few cm above the ground (diameter above roots, d_{ar}), using a caliper. Each seedling was measured twice, crosswise, and the average value was used for calculation and analysis. The total dry weight was determined at the end of the seedling period in the nursery by drying shoots and roots of the seedlings separately in an oven at 70°C during 24 hours. Shoot-root ratio of the seedling was calculated on a dry weight basis.

Statistical analysis used the General Statistic (Genstat) 5 release 3.2 software. Significant F-values established by Anova were further examined by comparisons of means according to the significant difference test of DMRT (Duncan Multiple Range Test).

Seedling preparation for the field experiment

Based on the experimental field design (see paragraph 3.2.2), four species of tree seedlings (mahogany, sungkai, candle nut and sukun) were prepared. The seedlings of each species were divided into two groups of 500 each. The first group was inoculated (+) and the other one was not inoculated (-) with the Mycofer. Inoculated and non-inoculated seedlings were also placed separately, so cross-infection through seedling media and water could be avoided. Seedling maintenance by watering and weeding was carried out until the end of the nursery phase.

3.2.2. Field Experiment

The field experiment consisted of two steps. The first step, as a main research, was an experiment designed by the researcher and was fully managed by the researcher with limited participation of farmers. The second step, as a developmental research, was an experiment designed by farmers, which was fully managed by the participating farmers.

Place and time of the experiment

The field plots were located in a transmigration area, some 20 to 27 km to the Northwest of Wanariset I Research Station, East Kalimantan, Indonesia (see par.2.1, 2.5 and Fig.2.1). The main study (the experiment designed by the researcher) was conducted within two years, from October 1999 to October 2001, while the developmental study (the experiment designed by farmer) was carried out within one year, from October 2000 to October 2001.

Experimental design

Research plots of the main study were set up according to a split plot block randomized design in a factorial experiment (Steel and Torrie, 1991; Gomez and Gomez, 1984).

The main plots represent mycorrhizal treatments :

- seedlings inoculated with mycorrhizal inoculum **(+)**
- seedlings not inoculated with mycorrhizal inoculum **(-)**

The sub-plots cover two factors:

- Tree species supplying shade (four tree species: Mahogany, *Swietenia macrophylla* King **(M)**; Sungkai, *Peronema canescens* Jack. **(Sa)**; Candle nut, *Aleurites moluccana* (L.) Willd. **(K)** and Sukun, *Artocarpus altilis* Fosberg. **(Su)**).
- *Imperata cylindrica* treatments (3 kinds: herbicide **(H)**; ploughing **(Pl)**; pressing, by pushing a heavy log over the grass **(Pr)**)

The main plots were set out three times as blocks. Every block consisted of two main plots and 2x4x3=24 sub-plots. Therefore, for all three blocks, there were 3x24=72 sub-plots, each with size of 8 x 16 m^2. The distance between every two sub-plots was 4 m and that between the two main plots was 6 m. Hence, the surface of every block was about 0.75 ha and the three together made 2.25 ha. The experimental plot layout of each main plot in the field can be seen on Fig. 3.1, while the layout of main plots at each block was presented on Fig.2.2.

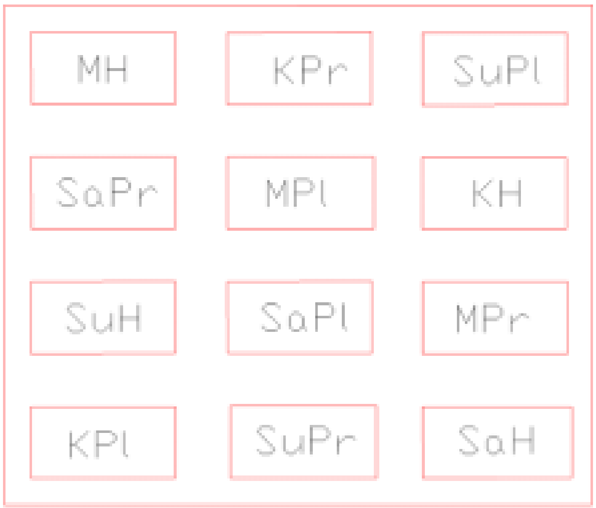


Fig.3.1. The experimental plot layout of each main plot in the field. M=Mahogany, Sa=Sungkai, K=Candle nut and Su=Sukun. H=herbicide, Pl=ploughing and Pr=pressing

Chapter 2 showed that these three blocks lie in different sites, with different soils and relief and were clustered. The three blocks may jointly represent the '*Imperata cylindrica* grasslands' of the area. Hence they are replications for the test of a 'blanket technology recipe'; they can, however, also be considered as representing three levels of a factor 'site quality', that can be defined on the basis of a priori information. This may allow for a fine tuning of the 'technology recipes' to the variation of conditions that exist in the field. Blanket technology recipes, as usually derived from replicated in agricultural experiments are always artificial in tropical rain forest zones. The validity of recognizing variation in site quality was demonstrated in Ivory Coast (Van Rompaey, 1993; Bonnéhin, 2000), Ethiopia (Kippie, 2002) and also in a recent greenhouse experiment in East Kalimantan (Omon, 2002). However, this unavoidable site heterogeneity is a compelling reason to review the meaning of the values measured and calculated. Indeed, the aim of alang-alang land conversion is precisely to upgrade the sites, to change them. Pioneer trees are chosen as tools for this purpose because of their capability to grow on a broad spectrum of degraded sites. It may be expected that site qualities will all converge over the years to similar values, due to the biological processes set in motion by these trees and the soil biota in particular. The sites, therefore, were ranked on a scale of 1 (rich) to 3 (poor), so as to pinpoint the initial state of the sites in the experimental process (for the underlying criteria see chapter 2).

Within the blocks, each including two main plots of 0.75 ha, there also was a considerable variation in soil properties. This variation occurred in patterns, of which the boundaries are not congruent with the rectangles of the experimental units in the split plot design (see map in Fig. 2.2 and 3.1). Now, natural boundaries are not sharp lines but transition zones, certainly at the scale of the sub-plots of 8x16 m^2 each, 24 per each block.

On the contrary, strong and clear limits are needed between treatments. There should be minimal fungal cross-contamination, so plots were artificially separated by gullies of 30 cm deep and 30 cm wide. This should be wide enough, as a distance of fungus movement was less than 30 cm (Smits, 1999, pers. comm.). *I. cylindrica* suppression could be limited precisely for ploughing and pressing one week before planting, but herbicide treatment one month before planting had to be carried out very carefully to avoid spillage or blow-over on neighbouring plots.

As an initial treatment, all plots were planted with a cover crop (*Pueraria javanica*) in between the young trees during the first year. Tree root systems and their rhizosphere bridge the differences between one soil and another over a certain width. This bridging effect was reinforced by the initial treatment of *Pueraria javanica* planting as a symbiotic N-fixing cover crop under the trees. A low dosage of fertilisation was applied to all tree seedlings in the three blocks at the transplanting time and six months afterwards. The fertiliser used was NPK (15-15-15) with a dosage of 30 g per tree seedling or equivalent to 4.5 g nitrogen (N), 4.5 g phosphorus (P) and 4.5 g potassium (K). The optimal dosage of fertiliser for young mahogany plantation on *grumusol* in East Java was 8.4 g N and 11.5 g P per tree seedling (Murniati and Mindawati, 1990). The fertiliser was sowed in a radius of 30 cm from the seedling and was covered with the soil around the planting hole.

The spacing of the trees was 4 x 2 m. Every subplot contained ca 25 seedlings. Timber trees (mahogany and sungkai) were planted in mono-culture, while multipurpose trees (candle nut and sukun) were mixed with timber trees. Candle nut was combined with mahogany and sukun with sungkai. In these plots, multipurpose trees act as main trees.

Research plots of the experiment designed by the farmers consisted of five blocks, with a size of 0.5 ha each block. The blocks were located separately and thus far from each other. There was no a certain experimental design suggested, so technically all things were arranged by the participating farmers themselves including *I. cylindrica* control method, tree spacing and plot maintenance.

Initial fungal flora existing in the field plots

Detailed observation of mycorrhizal fungi existing in the field plots of the main research area has been done before planting of the trees by means of soil and root samples collection and analysis. The soil samples collection was based on the locations of the plots (top/slope/valley). The results revealed the presence of several species of mycorrhizal fungi in the research sites as well as number of spores of those species per 50g soil samples (Table 3.1).

Planting and tending

After 5 months in the nursery, the seedlings were ready to be planted in the trial plots. Meanwhile, during the nursery period, some other preparations for the experiment were carried out such as treating *I. cylindrica*, producing the contour maps of the plots (see chapter 2) and digging the planting holes. The hole size was 30x30x30 cm^3. The plastic bags, which contained the seedlings or rooted cuttings were transported to the field plots and each was placed near a prepared hole. Prior to planting, each plastic bag was carefully removed, then the seedling was carefully planted with its soil clod intact. Finally, 30g of NPK fertiliser was sowed in a radius of 30 cm around the seedling and the hole was filled with soils from around the hole.

Until the age of one year, the tree plantation was maintained manually every three months by weeding in a 50 cm radius around the trees. Later, the plots were kept weed-free by means of annual food crop cultivation until the end of the observation period.

Observations and Measurements

As parameters of tree growth, the survival rate, stem height, stem diameter (diameter above root and at breast height) and crown diameter were measured. The survival rate, stem height and stem diameter (diameter above root, d_{ar}) were measured 3, 6, 12, 18 and 24 months after planting, while the diameter at the breast height (d_{bh}) was only measured 24 months after planting. This d_{bh} was measured so as to allow continued monitoring according to standard forestry parameters. The measurement values of stem height and stem diameter at 3 months after planting were recorded as initial stem height and stem diameter. So the height growth and diameter growth at 6, 12, 18 and 24 months were calculated based on those values. The total height was measured with a marked stick from the ground level to the end of growing point of the main axis. The diameter above roots was measured a few cm above the ground if no roots were visible, and above the roots if those could be seen.

Table 3.1. Morpho species and number of spores of naturally occurring mycorrhizal fungi over toposequences (top/slope/valley) at the initial condition of the research sites. Morpho species marked as 1 to 18 and named in the list of species below. The identification was done by the Forest Biotechnology Laboratory, Inter University Center of Biotechnology, Bogor Agricultural University

Posi-tion	Block	Total num-ber of spores	Number of spores of each morpho species																		Num ber of spe-cies
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
Top	1	21	3					11			6			1							4
	2	85		17				48			20										3
	3	18	3	1	1			10			1				2						6
Slope	1	283	73		18				77		11	54			46					4	7
	2	396	84		34	6			128		34	48			62						7
	3	441	91		37	6			119		28	93			67						7
Valley	1	616	158		180			184							94						4
	2	737	267	48			28			266	78		50								6
	3	619	217	24				24		238	54		62								6

List of morpho species serial number of mycorrhizal fungi presented on Table 3.1, 3.12 and 3.13
(morpho species number 15 to 17 and 19 to 26 appeared at the observation of 6 and 24 months after planting)

1. *Glomus* sp., black
2. *Glomus* sp., black-brown
3. *Glomus* sp., brown
4. *Glomus* sp., red
5. *Glomus* sp., red-yellow
6. *Glomus* sp., reddish-brown
7. *Glomus* sp., small reddish
8. *Glomus* sp., small red-brown
9. *Glomus* sp., yellow
10. *Glomus* sp., small-yellow
11. *Glomus* sp., yellowish brown
12. *Glomus occultum*
13. *Glomus* sp., hyaline
14. *Glomus* sp., small hyaline
15. *Glomus etunicatum*
16. *Glomus manihotis*
17. *Glomus* sp.
18. *Acaulospora* sp., red
19. *Acaulospora* sp., small yellow
20. *Accaulospora* sp., hyaline
21. *Accaulospora* sp., small hyaline
22. *Accaulospora* sp., brown
23. *Accaulospora* sp.
24. *Gigaspora* sp., yellow
25. *Gigaspora* sp.
26. *Scutellospora* sp., brown

The diameter at breast height was measured at 1.30 m above the ground level. The crown diameter was recorded 12, 18 and 24 months after planting. It was assessed twice, crosswise, and the average value was used for analysis, so transforming the true, irregular transverse section of the crown into a circle, was done for purposes of calculation. All the 25 trees per plot were measured.

The shading capacity per tree species was assessed by means of average relative shading on the ground with the following formula:

Relative shading = $100\ \% - (I_{l\ \text{above ground}}/I_{l\ \text{above canopy}} \times 100\ \%)$

Where I_l = Light Intensity

Light intensity was measured by using the Quantum LI-COR Radiation Sensor. The sensor measures photosynthetically active radiation (PAR) in the 400 to 700 nm wavebands. The unit of measurement is micro-moles radiation per second per square meter (μmol $s^{-1}m^{-2}$). This parameter was measured every six months (6, 12, 18 and 24 months after planting). The light intensity was measured at three trees per sub-plot, at 0,1 and 2 m from each trunk. Other parameters related to the shading capacity are leaf area indexes and crown surface.

The Leaf Area Index (LAI) was assessed by means of two methods, directly and indirectly. A direct method used a Psion Workabout machine. This equipment consists of a sensor with 100 cells and a digital recorder. The equipment measures light intensity above and below the canopy, as well as the LAI at the same time. An indirect method was derived from measured relative light intensity (I_l) below and above the tree canopy, and calculated according to Lambert-Beer's Law (Oldeman, 1974; Mousi and Saeki, 1953 *ex* Satoo and Madgwick, 1982; van Noordwijk and Lusiana, 1999) as follows :

$$I_l = e^{-k\,LAI} \quad \text{or} \quad LAI = \ln I_l/-k$$

for the light interception constant k a value of = - 0.7 was assumed (Van Noordwijk and Lusiana, 1999).

Crown surface (S_c) was assessed using the crown width/diameter (W_c) and was calculated assuming that form of the crown projection to the ground is a circle, with the formula :

$S_c = \pi \times W_c/2 \times W_c/2$, in which

S_c is Crown surface,
W_c is Crown width

Supporting data covering species and populations of mycorrhizal fungi and infected mycorrhizal roots were gathered by means of analysis of soil samples and root tissue samples. Those samples were taken in the rhizosphere, 6 and 24 month after tree planting according to the mycorrhizal treatment and the tree species. The analyses of the soil and root samples were carried out by the Laboratory of Forest Biotechnology, Inter-University Centre, Bogor Agricultural University.

Data processing

The average value of each variable was calculated separately per sub-plot. Then they were used as input data in the statistical analysis by means of General Statistic (Genstat) 5 release 3.2 software. Significant F-values established by Anova were further examined by comparisons of means according to significant difference tests as defined by the Duncan Multiple Range Test (DMRT). Supporting data covering species and populations of micro-organisms and infected mycorrhizal root data were discussed in relation to their dynamics.

The experiment designed by farmers

Five plots of the experiment were designed by farmers. That is to say that they were developed in full participation of the respective farmers. Tree species planted were approximately similar to the experiment designed by researcher. Two farmers planted Mahogany, *Swietenia macrophylla* and Sungkai, *Peronema canescens*; three other farmers cultivated Mahogany, Sungkai and Candle nut, *Aleurites moluccana*. The seedlings were provided by the project, and prepared by the researcher at the nursery of Wanariset Station. All methods used in the growing of seedlings, including seed germination, type of seedling containers, shading, watering and weeding were similar for all seedlings, including those prepared for the main research. A similar mycorrhizal treatment was implemented, one part of the seedlings was inoculated with mycorrhizal inoculum of the semi commercial product, "Mycofer" and another part was not. The seedlings were sent to the farmers five months later and planted by them according to their own method. However, the farmers were provided with the information that the seedlings of each tree species consisted of two different groups, named group A and B. It was suggested to the farmers to plant the two groups of seedling in separate places.

Observation and measurement was only focused on growth parameters of the tree species, covering survival, height and stem diameter. Measurements were done by the same method as in the main study. The only difference was the period of the observation, which was shorter, and the frequency was only three times, 4, 8 and 12 months after planting. The tree growth data were tabulated and recapitulated according to the tree species and the respective farmers.

3.3. RESULTS

3.3.1. Seedling Growth in The Nursery

Average height and diameter growth of the seedlings in the nursery for each of the tree species and mycorrhizal treatments are presented in Fig.3.2 and 3.3.

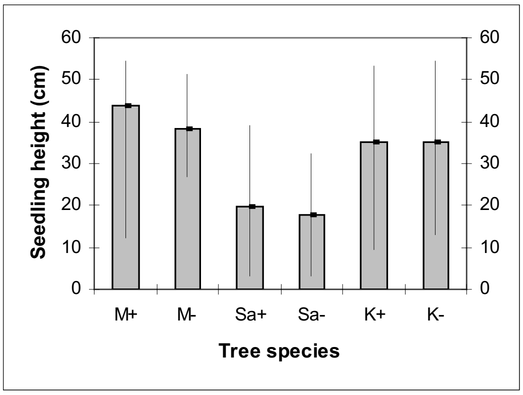


Fig.3.2. Average height (cm) of seedlings in the nursery. M=Mahogany, *Swietenia macrophylla*; Sa=Sungkai, *Peronema canescens*; K=Candle nut, *Aleurites moluccana*; inoculated (+) and not inoculated (-) with mycorrhizal fungi. The vertical lines on the bar indicate the data range

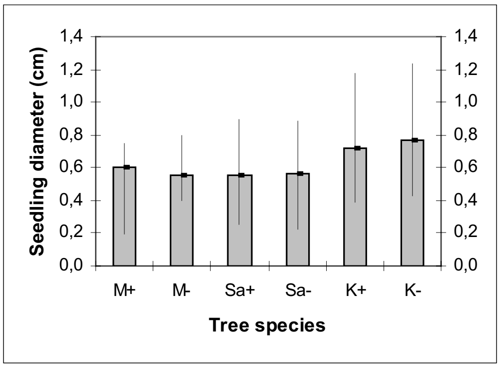


Fig.3.3. Average diameter (cm) of seedlings in the nursery. M=Mahogany, *Swietenia macrophylla*; Sa=Sungkai, *Peronema canescens*; K=Candle nut, *Aleurites moluccana*; inoculated (+) and not inoculated (-) with mycorrhizal fungi. The vertical lines on the bars indicate the data range

Statistical analysis of the average height of seedlings in the nursery showed significant differences among the three tree species. However, differences between mycorrhizal treatments were not significant. The same result was obtained for the average diameter of the seedlings. The diameter of sungkai (Sa) and candle nut (K) without mycorrhizae was even slightly higher than those with mycorrhizae. The effect of mycorrhizal treatment on the height and diameter of the seedling stem can be seen on Table 3.2.

The average dry weight of the seedling biomass, shoots and roots separately, and their ratio are shown in Fig.3.4, 3.5 and 3.6.

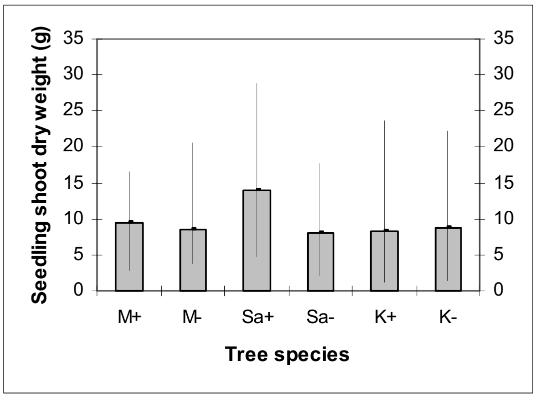


Fig.3.4. Average dry weight (g) of the seedling shoots biomass in the nursery. M=Mahogany, *Swietenia macrophylla*; Sa=Sungkai, *Peronema canescens*; K=Candle nut, *Aleurites moluccana*; inoculated (+) and not inoculated (-) with mycorrhizal fungi. The vertical lines on the bars indicate the data range

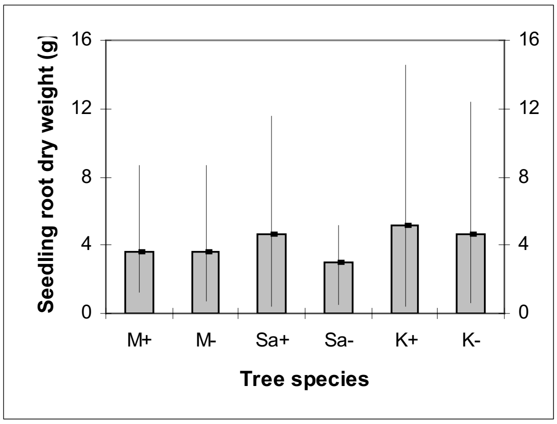


Fig.3.5. Average dry-weight (g) of the seedling roots biomass in the nursery. M=Mahogany, *Swietenia macrophylla*; Sa=Sungkai, *Peronema canescens*; K=Candle nut, *Aleurites moluccana*; inoculated (+) and not inoculated (-) with mycorrhizal fungi. The vertical lines on the bars indicate the data range

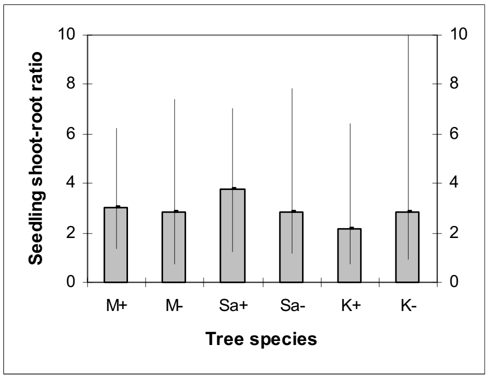


Fig.3.6. Average shoot-root ratio of the seedling biomass. M=Mahogany, *Swietenia macrophylla*; Sa=Sungkai, *Peronema canescens*; K=Candle nut, *Aleurites moluccana*; inoculated (+) and not inoculated (-) with mycorrhizal fungi. The vertical lines on the bars indicate the data range

Neither the average shoot and root dry weight of the seedlings, nor their shoot-root ratio were significantly different (see Table 3.2). In general the growth parameter of the seedlings that were inoculated with mycorrhizal fungi were higher than those without, except for the candle nut seedlings.

Table 3.2. Effect of mycorrhizal treatment on the seedling height, seedling diameter and biomass dry weight of the three tree species in the nursery. Numbers followed by different letters in the same column indicate significant (P<0.05) differences according to Duncan Multiple Range Test. NS=no significant difference (P>0.05). Interactions between main effects were not significant.

Treatment	Stem height (cm)	Stem diameter (cm)	Biomass dry-weight (g)		
			Shoot	Roots	Shoot-root ratio
Mycorrhizal fungi					
Inoculated (+)	32.9^{NS}	0.6^{NS}	10.5^{NS}	4.5^{NS}	3.0^{NS}
Not inoculated (-)	30.4	0.6	8.4	4.5	2.8
Tree Species					
Mahogany (M)	41.1^{a}	0.6^{b}	9.0^{NS}	4.8^{NS}	2.8^{NS}
Sungkai (Sa)	18.7^{b}	0.6^{b}	11.0	3.8	3.3
Candle nut (K)	35.1^{a}	0.8^{a}	8.4	4.9	2.5

3.3.2. Growth of Tree Species in the Field

This paragraph mainly presents the tree growth variables of the main study, whereas growth of the tree species planted by farmers is presented in the subsequent paragraph.

Survival rates

The survival rate of trees in a plantation is the most important criterion in determining which tree species are suitable to be planted. This is also true on degraded *I. cylindrica* (alang-alang) grassland. This variable was influenced either by the seedling quality or the site quality or both. In this study, an attempt was made to improve seedling quality by means of inoculation of the young seedling with mycorrhizal fungi. The effect of mycorrhizal treatment and *I. cylindrica* management on the survival rates of four tree species (*Swietenia macrophylla*, Mahogany; *Peronema canescens*, Sungkai; *Aleurites moluccana*, Candle nut and *Artocarpus altilis*, Sukun) which were planted on the degraded alang-alang grassland can be seen in Fig. 3.7 and Table 3.3.

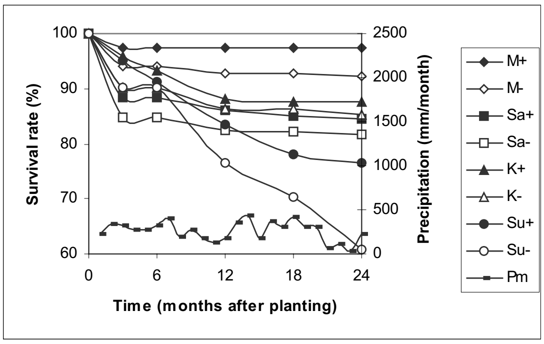


Fig. 3.7. Survival rate (%) of the four tree species (M=Mahogany, *Swietenia macrophylla*; Sa=Sungkai, *Peronema canescens*; K=Cancle nut, *Aleurites moluccana* and Su=Sukun, *Artocarpus altilis*), inoculated (+) and not inoculated (-) mycorrhyzal fungi, respectively. P_m is monthly precipitation during the first two years of the tree plantation.

These mortality patterns are different. Nearly all mahogany and sungkai trees that survived the first three months, survived until the last observation. For candle nut, however, tree mortality continued till the age of 12 months and for sukun till 24 months. In the period of 8 to 12 months after planting, the survival rate of all tree species decreased, except for mahogany inoculated with mycorrhizal fungi. This is tightly correlated to the precipitation in the period, less than 200 mm per month on the average. In the period of 21 to 23 months after planting, precipitation dropped sharply to a very low level. However, this condition did not affect the survival rate of most tree species during that late period, except for sukun, both inoculated and not inoculated with mycorrhizal fungi. There was a tendency for continuing of sukun mortality.

Table 3.3. Effect of mycorrhizal treatment and *I. cylindrica* management on the survival rate of four tree species 3, 6, 12, 18 and 24 months after planting. Numbers followed by different letters, a, b or c in the same column indicate significant ($P<0.05$) differences according to Duncan's Multiple Range Test. NS=not significantly different ($P>0.05$))

Treatments/ Blocks	Survival (%)				
	3 months	6 months	12 months	18 months	24 months
Mycorrhyzal fungi					
Inoculated (+)	94.5^{a}	92.4^{a}	88.8^{NS}	87.0^{a}	86.5^{a}
Not inoculated (-)	89.8^{b}	89.8^{b}	84.5	82.8^{b}	80.0^{b}
Tree Species					
Mahogany (M)	95.6^{a}	95.6^{a}	95.1^{a}	95.1^{a}	94.8^{a}
Sungkai (Sa)	86.7^{b}	86.7^{b}	84.3^{ab}	83.6^{ab}	83.0^{a}
Candle nut (K)	93.5^{ab}	91.3^{ab}	87.2^{ab}	86.9^{ab}	86.5^{a}
Sukun (Su)	92.7^{ab}	90.6^{ab}	80.0^{b}	74.2^{b}	68.6^{b}
***Imperata cylindrica* management**					
Herbicide (H)	90.7^{NS}	89.9^{NS}	82.7^{NS}	80.7^{NS}	78.2^{NS}
Ploughing (Pl)	92.9	91.1	90.1	88.6	87.9
Pressing (Pr)	92.7	92.1	87.2	85.6	83.6
Blocks					
First	91.6	90.2	87.4	85.7	83.3
Second	90.8	89.1	83.6	82.5	80.8
Third	93.9	93.9	88.9	86.7	85.6

Statistical analysis of the survival data for 3, 6, 12, 18 and 24 months after planting showed no significant interaction among the treatments, mycorrhizae, tree species and alang-alang management. Table 3.3 therefore shows data for the main effects only. Seedlings inoculated with mycorrhyzal fungi (+) had a higher survival rate than without (-). The differences are statistically significant ($P<0.05$) for 3, 6,18 and 24 months after planting, but not after 12 months. The survival rate of mahogany was similar to those of candle nut and sukun, but it was significantly higher than sungkai survival at 3 and 6 months. Observations made after 12 and 18 months showed, that the mahogany survival was significantly higher than in sukun, but similar to sungkai and candle nut. At 24 months observation, the survival rates of mahogany, sungkai and candle nut were similar, and all were significantly higher than that of sukun.

No significant differences were found among the three methods of *I. cylindrica* management as to their influence on the survival rate of the four tree species.

The survival rates among the three blocks for all five observations were slightly different. The survival at the third block was consistently highest, followed by the first block and the second block came latest.

Diameter growth

Figure 3.8 presents the growth of the stem diameter above roots of the four tree species 6, 12, 18 and 24 months after planting, while the effects of mycorrhizal treatment and *I. cylindrica* management on the diameter of those tree species are shown on Table 3.4.

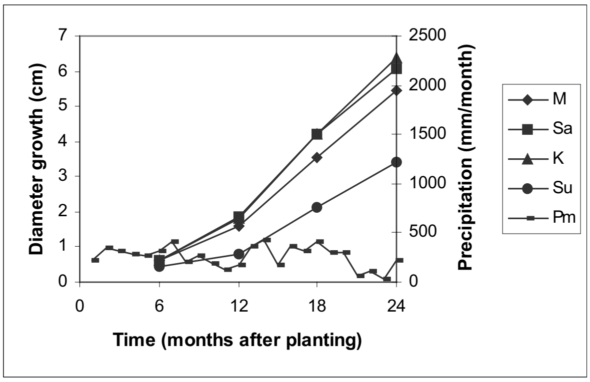


Fig. 3.8. Growth of stem diameter of four tree species. M=Mahogany, *Swietenia macrophylla*; Sa=Sungkai, *Peronema canescens*; K=Candle nut, *Aleurites moluccana* and Su=Sukun, *Artocarpus altilis*. P_m is monthly precipitation during the first two years after tree plantation.

The diameter growth of mahogany, sungkai and candle nut over this period follows an approximately linear curve. During a period of 6 to 12 months after planting, the growth was lower than afterwards. Actually, the diameter growth rate curves of those three tree species had smaller slope to the x-coordinate than to the y-coordinate. The diameter growth of sukun was extremely lower than that of the other tree species, particularly within the period of 6 to 12 months after planting.

Table 3.4 shows that the effects of mycorrhizal treatment did not significantly boost the diameter growth of the four tree species over 24 months (the period from inoculation to 24 months). Diameter growth of mahogany, sungkai and candle nut was similar to that of those at 6, 12, 18 and 24 months after planting. They were significantly higher than sukun, except in the 18 months observation. At that time, the diameter growth of mahogany was similar to sukun. Herbicide and ploughing treatment of alang-alang significantly stimulated early diameter growth of the trees (6 months after planting), as compared with pressing. After that the alang-alang treatment has not significantly increased the growth of diameter.

Among the blocks, the diameter growth quite varied, especially for the observation made at 12, 18 and 24 months after planting. The diameter growth at the second block was always lowest.

Table 3.4 Effect of mycorrhizal treatment and *I. cylindrica* management on the average diameter growth of four tree species 6, 12, 18 and 24 months after planting. Numbers followed by different letters in the same column indicate significant (*P< 00.5*) differences according to Duncan's Multiple Range Test. NS=not significant different (*P>0.05*))

Treatments/Blocks	Average Diameter Growth (cm)			
	6 months	12 months	18 months	24 months
Mycorrhyzal fungi				
Inoculated (+)	0.6^{NS}	1.5^{NS}	3.3^{NS}	5.1^{NS}
Not inoculated (-)	0.6	1.5	3.7	5.6
Tree Species				
Mahogany (M)	0.6^{a}	1.6^{a}	3.5^{ab}	5.5^{a}
Sungkai (Sa)	0.6^{a}	1.8^{a}	4.2^{a}	6.1^{a}
Candle nut (K)	0.6^{a}	1.8^{a}	4.2^{a}	6.4^{a}
Sukun (Su)	0.5^{b}	0.8^{b}	2.1^{b}	3.4^{b}
***I.cylindrica* management**				
Herbicide (H)	0.6^{a}	1.6^{NS}	3.7^{NS}	5.5^{NS}
Ploughing (Pl)	0.6^{a}	1.6	3.6	5.5
Pressing (Pr)	0.5^{b}	1.4	3.2	4.9
Blocks				
First	0.6	1.7	4.5	6.6
Second	0.5	1.0	2.2	3.6
Third	0.7	1.8	3.9	5.8

Height growth

The height growth of four tree species from 6 to 24 months after planting is presented on Figure 3.9, while the effects of mycorrhyzal treatment and alang-alang management on height growth can be seen in Table 3.5.

Fig.3.9 shows that the height growth of mahogany, sungkai and candle nut over the time were similar. Candle nut height growth was consistently somewhat higher than that of the other 3 species for the whole period. The height growth of sukun was very low, particularly in the period of 6 to 12 months after planting, when precipitation was low. Its height growth remains the lowest of all four species over the observation period.

Table 3.5 shows that mycorrhizal treatment had no significant effect on the height growth of the four tree species until the end of research period. *I. cylindrica* management (6 months after planting) by using herbicide and ploughing significantly stimulated the height growth as compared with pressing. No significant remaining differences among the treatments were found at the later times.

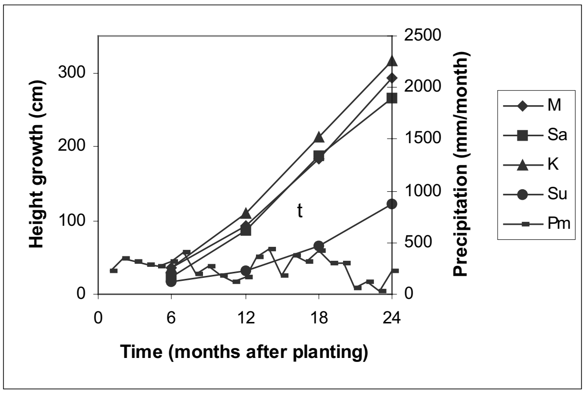


Fig. 3.9. Height growth of four tree species until 24 months after planting. M=Mahogany, *Swietenia macropyilla*; Sa=Sungkai, *Peronema canescens*; K=Candle nut, *Aleurites moluccana* and Su=Sukun, *Artocarpus altilis*. P_m is monthly precipitation during the observation period.

Table 3.5. Effect of mycorrhizal treatment and *I.cylindrica* management on the height growth of four tree species, 6, 12, 18 and 24 months after planting. Numbers followed by different letters in the same column indicate significant (*P< 0.05*) differences according to Duncan's Multiple Range Test. NS=not significantly different (*P>0.05*))

Treatments/Blocks	Average Height Growth (cm)			
	6 months	12 months	18 months	24 months
Mycorrhyzal fungi				
Inoculated (+)	30.8^{NS}	81.3^{NS}	158.6^{NS}	239.3^{NS}
Not inoculated (-)	25.9	79.0	166.5	259.3
Tree Species				
Mahogany (M)	35.8^{a}	92.4^{a}	182.4^{a}	292.1^{a}
Sungkai (Sa)	24.1^{b}	86.1^{a}	188.3^{a}	265.5^{a}
Candle nut (K)	35.9^{a}	109.6^{a}	213.6^{a}	317.2^{a}
Sukun (Su)	17.5^{b}	32.5^{b}	66.0^{b}	122.5^{b}
***I.cylindrica* management**				
Herbicide (H)	33.2^{a}	87.8^{NS}	176.5^{NS}	258.3^{NS}
Ploughing (Pl)	29.8^{a}	83.5	165.2	254.1
Pressing (Pr)	22.0^{b}	69.2	146.1	235.5
Blocks				
First	29.3	96.1	197.9	305.9
Second	25.3	49.4	109.3	182.5
Third	30.5	95.0	180.6	259.6

Wood volume

Wood volume is a growth parameter that is affected by both diameter and height increment as well as by a stem form factor. Tree species usually have different stem form factors. However, in the current analysis the stem form factor is assumed to be the same for all four species i.e. 0.6 (Wahjono and Soemarna, 1987), in view of their juvenile state. Therefore the wood volume can be calculated as:

$v = 0.6 * \frac{1}{4} \pi * d^2 * h$, in which:
v = wood volume
d = stem diameter (diameter above root)
h = total height

Average wood volume of the four tree species after mycorrhizal treatment and alang-alang management is presented in Table 3.6

Table 3.6. Average wood volume of four tree species after mycorrhizal treatment and *I.cylindrica* management, 18 and 24 months after planting. Numbers followed by different letters in the same column indicate significant differences ($P < 0.05$) according to Duncan's Multiple Range Test.
NS=not significantly different ($P > 0.05$)

Treatments	Average wood volume (cm^3/tree)	
	18 months	24 months
Mycorrhyzal fungi		
Inoculated (+)	933^{NS}	2754^{NS}
Not inoculated (-)	1412	4456
Tree Species		
Mahogany (M)	1683^a	5309^a
Sungkai (Sa)	2296^a	5970^a
Candle nut (K)	1754^a	5433^a
Sukun (Su)	257^b	875^b
***I.cylindrica* management**		
Herbicide (H)	1387^{NS}	4130^{NS}
Ploughing (Pl)	1253	3837
Pressing (Pr)	873	2710

The effect of mycorrhyzal treatment was not significantly correlated to wood volume. The wood volumes of mahogany, sungkai and candle nut were similar to each other and all were significantly different from sukun. Sukun had the lowest wood volume. Alang-alang treatments did not show any significant correlation with wood volume.

Shading capacity

Relative shading under the canopy (0 m from the trunk) of the four tree species at 6, 12, 18 and 24 months after planting is presented in Fig. 3.10 and Table 3.7).

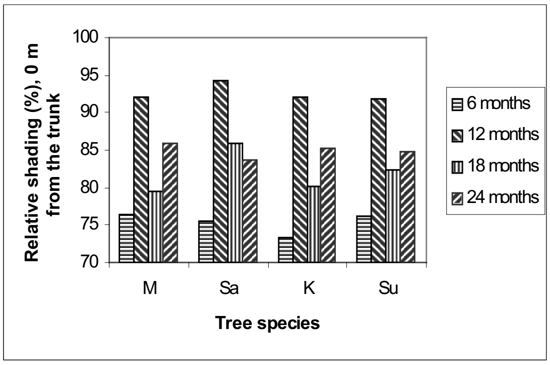


Fig 3.10. The relative shading under the canopy of the four tree species (M=Mahogany, *Swietenia macrophylla*; Sa=Sungkai, *Peronema canescens*; K=Candle nut, *Aleurites moluccana* and Su=Sukun, *Artocarpus altilis*) at 6, 12, 18 and 24 months after planting, 0 m from the trunk.

Fig.3.10 shows that the relative shading of the four tree species fluctuates during the first 24 months after planting. It increased sharply between 6 and 12 months after planting and then declined. The highest relative shading at 6 and 24 months after planting occurred under Mahogany, while at 12 and 18 months it was found under Sungkai. The relative shading under the canopy was similar for the four tree species.

The decrease of relative shading between 12 and 18 months after planting can be explained by seasonal differences. At the 15th months after planting (December 2000), the amount of rainfall suddenly dropped and, during this period, most of the leaves were torn off by strong winds. Later, in the period from the 16th to 18th months after planting, the rainfall rates returned to normal and even above normal with ranges of 310 to 415 mm month^{-1}. However, the three wet months were not enough for young leaves to recover, so the relative shade at 18th months after planting was lower than previously. Finally, in the period from 21st to 23rd months after planting, long period of drought occurred in the research sites. Precipitation during those periods decreased to the lowest amount. During this time, most of the leaves and twigs of the trees, particularly sungkai, were yellowing, drying and they fell down. In the 24th month after planting, precipitation increased to the normal level. New young leaves emerged in this last observation. Therefore, the relative shading under the canopy rose again, but it remained lower than the value at 12 months.

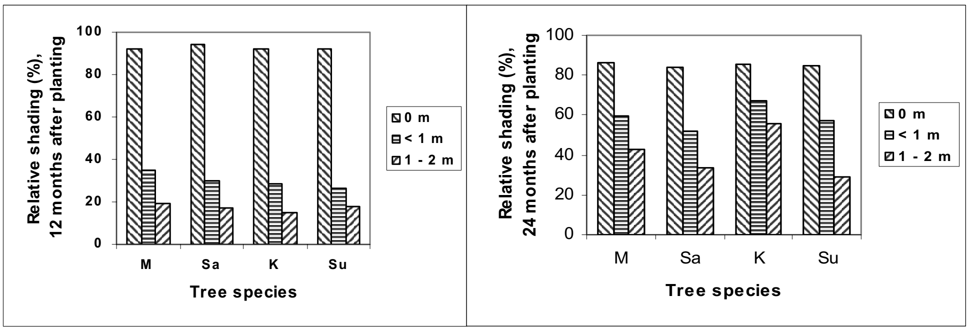
Tabel 3.7 shows that mycorrhizal treatment does not lead to higher relative shading by the four tree species over the time. Alang-alang management by pressing has a tendency toward lowering the relative shading by the tree species, but we can not reject the null-hypothesis of no difference among the methods of *I. cylindrica* management. Apparently, the relative shading under the canopy of sungkai tends to be highest among the tree species until 18 months after planting. After that it fell to the lowest place. This is tightly correlated with the condition of the crown of the sungkai, where most of the leaves and twigs were yellowing, drying and they fell down during a long period of drought (from 21 to 23 months after planting). Among the four tree species, it seems that the crown of sungkai is most affected by the drought.

Table 3.7. Effect of mycorrhizal treatment and *I. cylindrica* management on relative shading by the four tree species, at 6, 12, 18 and 24 months after planting, 0 m from the trunk. NS=not significantly different, P>0.05))

Treatments	Average Relative Shading (%)			
	6 months	12 months	18 months	24 months
Mycorrhyzal fungi				
Inoculated (+)	74.6^{NS}	92.6^{NS}	78.3^{NS}	84.7^{NS}
Not inoculated (-)	76.1	92.4	85.7	85.1
Tree Species				
Mahogany (M)	76.5^{NS}	92.0^{NS}	79.5^{NS}	85.9^{NS}
Sungkai (Sa)	75.6	94.2	85.9	83.7
Candle nut (K)	73.2	92.0	80.2	85.2
Sukun (Su)	76.1	91.9	82.4	84.9
***I.cylindrica* management**				
Herbicide (H)	74.8^{NS}	93.0^{NS}	83.5^{NS}	86.4^{NS}
Ploughing (Pl)	78.8	93.0	83.2	84.2
Pressing (Pr)	72.4	91.5	79.4	84.1

Relative shading by the four tree species became lower with the distance from the trunk.

The farther from the trunk, the lower the relative shading. Figure 3.11 and Table 3.8 show the average relative shading at various distances from the trunk, 12 and 24 months after planting. Relative shading at 0 m from the trunk at 12 months after planting was higher than at 24 months for all four tree species. However, for 1 and 2 m from the trunk, the relative shading at 24 months was higher than at 12 months for all trees. Mycorrhizal treatment and *I. cylindrica* management did not lead to a significant effect on the relative shading 0, 1 and 2 m from the trunk, either at 12 or at 24 months after planting. Relative shading of the four tree species was similar, except for 1 and 2 m from the trunk at 24 months after planting. The highest value was than found for candle nut, both for 1 and 2 m from the trunk, while the lowest one occurred for sungkai at 1 m and for sukun at 2 m from the trunk.



A B

Fig 3.11. Relative shading (%) of the four tree species (M=Mahogany, *Swietenia macrophylla*; Sa=Sungkai, *Peronema canescens*; K=Candle nut, *Aleurites moluccana* and Su=Sukun, *Artocarpus altilis*) at 12 months (A) and 24 months (B) after planting, 0, 1 and 2 m from the trunk.

Table 3.8. Effect of mycorrhizal treatment and *I. cylindrica* management on relative shading by the four tree species at various distances from the trunk, 12 and 24 months after planting. Numbers followed by different letters, a, b or c in the same column indicate significant (*P<0.05*) differences according to Duncan's Multiple Range Test, NS=not significantly different, P>0.05)

Treatments	Average Relative Shading (%)					
	12 months			24 months		
	0 m	1 m	2 m	0 m	1 m	2 m
Mycorrhyzal fungi						
Inoculated (+)	92.6^{NS}	24.4^{NS}	16.2^{NS}	84.7^{NS}	57.3^{NS}	43.0^{NS}
Not inoculated (-)	92.4	35.5	18.5	85.1	60.6	37.4
Tree Species						
Mahogany (M)	92.0^{NS}	34.9^{NS}	19.1^{NS}	85.9^{NS}	59.9^{ab}	42.7^{ab}
Sungkai (Sa)	94.2	29.7	17.3	83.7	51.6^{b}	33.6^{b}
Candle nut (K)	92.0	28.7	14.9	85.2	67.1^{a}	55.5^{a}
Sukun (Su)	91.9	26.4	18.1	84.9	57.1^{ab}	29.0^{b}
***I.cylindrica* management**						
Herbicide (H)	93.0^{NS}	33.0^{NS}	18.2^{NS}	86.4^{NS}	61.7^{NS}	42.0^{NS}
Ploughing (Pl)	93.0	27.8	17.9	84.2	57.4	39.1
Pressing (Pr)	91.5	29.0	15.9	84.1	57.7	39.5

Leaf area index and crown surface

Leaf area index (LAI) of the four tree species at 6, 12, 18 and 24 months after planting, 0 m from the tree trunk based on the indirect method presented on

Fig.3.12, whereas effects of mycorrhizal fungi and alang-alang management on the LAI are described in Table 3.9.

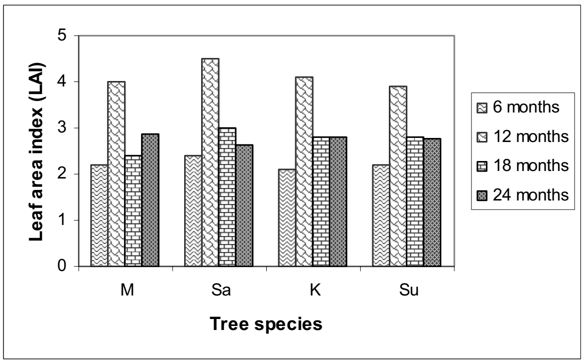


Fig. 3.12. Leaf Area Index (LAI) of the four tree species (M=Mahogany, *Swietenia macrophylla*; Sa=Sungkai, *Peronema canescens*; K=Candle nut, *Aleurites moluccana* and Su=Sukun, *Artocarpus altilis*) at 6, 12, 18 and 24 months after planting

Table 3.9. Effect of mycorrhizal treatment and *I. cylindrica* management on Leaf Area Index (LAI) of the four tree species, at 6, 12, 18 and 24 months after planting, 0 m from the tree trunk. Values followed by different letters in the same column indicate significant differences according to Duncan's Multiple Range Test (*P<0.05*). NS=not significantly different (P>0.05)

Treatments	Average Leaf Area Index (LAI)			
	6 months	12 months	18 months	24 months
Mycorrhyzal fungi				
Inoculated (+)	2.24^{NS}	3.88^{NS}	2.35^{NS}	2.78^{NS}
Not inoculated (-)	2.18	4.36	3.16	2.76
Tree Species				
Mahogany (M)	2.21^{NS}	3.97^{b}	2.40^{b}	2.87^{NS}
Sungkai (Sa)	2.38	4.55^{a}	3.01^{a}	2.63
Candle nut (K)	2.07	4.09^{ab}	2.80^{ab}	2.80
Sukun (Su)	2.20	3.87^{b}	2.79^{ab}	2.78
***I.cylindrica* management**				
Herbicide (H)	2.19^{NS}	4.12^{NS}	2.85^{NS}	2.89^{NS}
Ploughing (Pl)	2.38	4.15	2.86	2.71
Pressing (Pr)	2.08	4.09	2.55	2.71

Fig. 3.12 points that LAI of the four tree species fluctuated over times. It increased sharply during the period of 6 to12 months after planting. After that it decreased dramatically (at 18 months) and then tends to stabilise (at 24 months). The decreasing LAI might well be caused by leaf fall as explained in the previous paragraph. The LAI of Sungkai is the highest of the four species until 18 months. However, it became the lowest one at 24 months. Indeed, the mycorrhizal treatment and the alang-alang management did not affect significantly LAI.

Mycorrhizal treatment had no significant effect on the LAI of the tree species (Table 3.9). Neither was LAI affected significantly by alang-alang treatment. However, there was a tendency towards a higher LAI with ploughing. At the beginning, i.e. 6 months after planting, the LAI among the four tree species was not significantly different. However, at the second and third observation point, LAI values were significantly different among the tree species.

Fig.3.13 shows the crown surface of the four tree species at 12,18 and 24 months after planting. The effect of mycorrizal fungi and alang-alang management on the crown surface can be seen in Table 3.10.

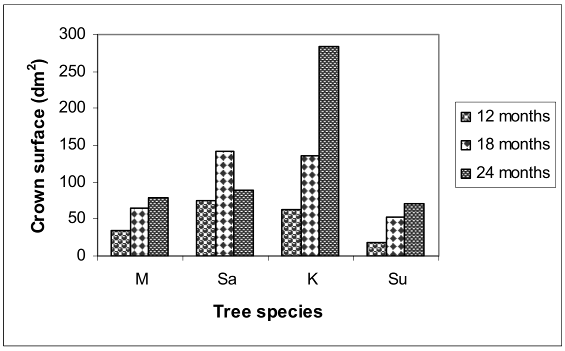


Fig. 3.13. Crown surface of the four tree species (M=Mahogany, *Swietenia macrophylla*; Sa=Sungkai, *Peronema canescens*; K=Candle nut, *Aleurites moluccana* and Su=Sukun, *Artocarpus altilis*) 12, 18 and 24 months after planting

Table 3.10. Effect of mycorrhizal treatment and *I. cylindrica* management on the crown surface of the four tree species 12, 18 and 24 months after planting. Values followed by different letters indicate significant differences (*P<0.05*) according to Duncan's Multiple Range Test. NS=not significant different (*P>0.05*).

Treatments	Crown Surface (dm^2)		
	12 months	18 months	24 months
Mycorrhyzal fungi			
Inoculated (+)	47.0^{NS}	84.1^{NS}	95.7^{NS}
Not inoculated (-)	48.5	95.1	123.9
Tree Species			
Mahogany (M)	35.1^{b}	64.1^{b}	78.7^{b}
Sungkai (Sa)	74.8^{a}	141.3^{a}	88.3^{b}
Candle nut (K)	63.1^{a}	136.5^{a}	284.5^{a}
Sukun (Su)	18.0^{b}	51.8^{b}	71.1^{b}
***I.cylindrica* management**			
Herbicide (H)	54.9^{NS}	100.9^{NS}	115.4^{NS}
Ploughing (Pl)	49.2	93.1	115.6
Pressing (Pr)	39.2	76.4	96.8

Mycorrhizal treatment and alang-alang management did not lead to significant effects on the crown surface of the tree species. Candle nut has the highest crown surface among the four tree species at 24 months after planting. It differs significantly from mahogany, sungkai and sukun. However, at 12 and 18 months, the crown surface of sungkai was largest.

3.3.3. Dynamics of the Mycorrhizal Fungi

The effects of mycorrhizal treatment, planting of several tree species and position of the plot on species and population of mycorrhizal fungi as well as the proportion of infected tree roots, 6 and 24 months after tree planting are shown in Table 3.11.

In the initial condition, the number of spores on the top of the plots was significantly lower than on the slope and in the valley; it was highest at the valley. However, 6 and 24 months after tree planting, there were no significant differences any more among those positions of the plots. Application of mycorrhizal inoculum to the seedlings was almost without effect on species and spore number of the mycorrhizal fungi present in 50 g soil. Neither did it affect the percentage of infected roots found 6 and 24 months after planting. It only increased the number of species of mycorrhizal fungi significantly after 24 months.

Table 3.11. Effects of mycorrhizal treatment and tree plantation on the species and spore numbers of mycorrhizal fungi per 50 g soil and the rate of infected mycorrhizal roots, 6 and 24 months after tree planting. Numbers followed by different letters, a, b or c in the same column indicate significant (*P<0.05*) differences according to Duncan's Multiple Range Test. NS=not significantly different (*P>0.05*), na=no data available

Treatments	Initial condition		6 months		24 months		Infected tree roots (%)	
	species	spores	species	spores	species	spores	6 months	24 months
Mycorrhyzal fungi								
Inoculated (+)	-	-	4^{NS}	104^{NS}	3^{a}	11^{NS}	87^{NS}	37^{NS}
Not inoculated (-)	-	-	4	102	2^{b}	11	85	51
Tree Species								
Mahogany (M)	-	-	3^{b}	98^{NS}	2^{NS}	10^{NS}	87^{ab}	43^{NS}
Sungkai (Sa)	-	-	5^{a}	110	2	10	87^{ab}	46
Candle nut (K)	-	-	4^{a}	109	2	14	93^{a}	36
Sukun (Su)	-	-	4^{a}	95	3	11	77^{b}	51
Plot position								
Top	4^{NS}	41^{c}	5^{NS}	94^{NS}	na	na	85^{NS}	na
Slope	7	373^{b}	4	115	na	na	86	na
Valley	5	657^{a}	4	101	na	na	88	na

The number of species of VA mycorrhizal fungi present in the rhizosphere of sungkai, candle nut and sukun six months after planting was significantly higher than that of mahogany. However, an observation 24 months after planting did not show any significant difference among those four tree species, either in number of species or in number of spores of the mycorrhizal fungi. The percentage of infected tree roots was not affected by inoculation with mycorrhizal fungi. It neither differed according to the position of the plots (top/slope/valley). However, the infected roots of the four tree species had been significantly different 6 months after planting. Roots of sukun showed the lowest infection at 6 months, but it showed the highest at 24 months.

The status, species diversity and number of spores of mycorrhizal fungi in 50 g soil samples, 6 and 24 months after tree planting can be seen in Table 3.12 and 3.13.

Comparison between the initial data (before planting the tree species, see Table 3.1) and data taken at 6 and 24 months after tree planting (Table 3.12 and 3.13), showed a decrease in mycorrhizae, either in number of species or in number of spores per 50 g soil. The average species number decreased from 6 to 4 (6 months) and only 3 species of mycorrhizal fungi remained per tree species per sub plot at the end of study (24 months after planting). Whereas the number of spores decreased from 357 to 102 (6 months); at the end of this study it had steadily decreased to a minimum number, i.e. 12 spores per 50 g soil sample. The latter decrease is quite significant.

Table 3.12. Number of morpho species and spores of mycorrhizal fungi per 50 g soil under four tree species (M=mahogany, *Swietenia macrophylla*, Sa=sungkai, *Peronema canescens*, K=candle nut, *Aleurites moluccana* and Su=sukun, *Artocarpus altilis*), inoculated (+) and not inoculated (-) mycorrhizal fungi over toposequences (T=top,S=slope,V=valley), 6 months after planting the trees. Name of morpho species marked here as 1 to 26 are identified on the list in par. 3.2.2.

Tree species	Treatment	Position	Block	Number of spores	Morpho species of mycorrhizal fungi and number of spores of each																										Number of species
					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	
M	+	T	1	257	114					134													4							5	4
M	+	T	2	36	16					16								4													3
M	+	T	3	123	13					32								76												2	4
M	+	S	1	165	14		4			30								94										23			5
M	+	S	2	120	20					100																					2
M	+	S	3	111	9					47								45					3					7			5
M	+	V	1	29						9								20													2
M	+	V	2	67	10					57																					2
M	+	V	3	136	5					113													10					6		2	5
M	-	T	1	117	2					113																				2	3
M	-	T	2	20	2					18																					2
M	-	T	3	99	7					44			3					38					2					5			6
M	-	S	1	120	4					90								10										14		2	5
M	-	S	2	40						40																					1
M	-	S	3	43	8					18													6					11			4
M	-	V	1	113	3					99								8										3			4
M	-	V	2	84						84																					1
M	-	V	3	77	6					19								52													3
Sa	+	T	1	84	6					38								35							4			1			5
Sa	+	T	2	65	15					30													20								3
Sa	+	T	3	91	42					36								2					3					8			5
Sa	+	S	1	159	7					12													129					11			4
Sa	+	S	2	132	12					85													30					5			4
Sa	+	S	3	52	5					33								4					3					7			5
Sa	+	V	1	119	15					57								26					8					13			5
Sa	+	V	2	181	9					149								8					2					13			5
Sa	+	V	3	78	19		5			28								14					5	4				3			7
Sa	-	T	1	120						40								35												45	3
Sa	-	T	2	52	9					35													8								3
Sa	-	T	3	75	15		3			16								23					10					8			6
Sa	-	S	1	215	15					97								45					20					36		2	6
Sa	-	S	2	133	36					97																					2
Sa	-	S	3	109	9					50								34					15					1			5
Sa	-	V	1	151	3					119								6					11					12			5
Sa	-	V	2	113	17					73								19										4			4
Sa	-	V	3	55	3		8			21								9										14			5

Table 3.12 (continued)

Tree species	Treatment	Position	Block	Number of spores	Morpho species of mycorrhizal fungi and number of spores of each																										Number of species
					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	
K	+	T	1	13						9								4													2
K	+	T	2	172	35					130													3					4			4
K	+	T	3	59	2		18			25								1										13			5
K	+	S	1	139	19					72				44																4	4
K	+	S	2	81	21					50								10													3
K	+	S	3	102	5		9			26								62													4
K	+	V	1	121	10					25								50					21					15			5
K	+	V	2	64	14					24													25					1			4
K	+	V	3	218	60					127			2										20					9			5
K	-	T	1	80	16					62				1																1	4
K	-	T	2	67	3					36													2		26						4
K	-	T	3	106	22					68								16													3
K	-	S	1	73	4					25													38					6			4
K	-	S	2	131	19					102																		10			3
K	-	S	3	144	9					77								56										2			4
K	-	V	1	73	17					54																		2			3
K	-	V	2	173	30					138													4					1			4
K	-	V	3	145	36					55								8					40					6			5
Su	+	T	1	181	5					56								77					31			1		11			6
Su	+	T	2	77	28					27								20										2			4
Su	+	T	3	19	3					4													10					2			4
Su	+	S	1	131	2					102								12					8					7			5
Su	+	S	2	85	17					65																		3			3
Su	+	S	3	47	7					30								5					1					4			5
Su	+	V	1	29						9								20													2
Su	+	V	2	67	10					57																					2
Su	+	V	3	136	5					113													10					6		2	5
Su	-	T	1	243	23					216																		2		2	4
Su	-	T	2	46	2					40													2					2			4
Su	-	T	3	43	8					31								4													3
Su	-	S	1	109	6					47													44					12			4
Su	-	S	2	148	105					43																					2
Su	-	S	3	163	7					121													22					13			4
Su	-	V	1	59	1					28													22					6		2	5
Su	-	V	2	81	16					47								10					8								4
Su	-	V	3	45	2					19			3					7					10					4			6

Table 3.13. Number of morpho species and spores of mycorrhizal fungi per 50 g soil under four tree species (M=mahogany, *Swietenia macrophylla*, Sa=sungkai, *Peronema canescens*, K=candle nut, *Aleurites moluccana* and Su=sukun, *Artocarpus altilis*), inoculated (+) and not inoculated (-) with mycorrhizal fungi, 24 months after planting the trees. Name of morpho species marked here as 1 to 26 are identified on the list in par.3.2.2

Tree species	Treatment	Block	Number of spores	Morpho species of mycorrhizal fungi and number of spores of each																										Number of species
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	
M	+	1	5	2														3												2
M	+	2	10	8								2																		2
M	+	3	3									3																		1
M	-	1	16															16												1
M	-	2	7	3								1						3												3
M	-	3	17															16		1										2
		1																												
Sa	+	2	10	5														4	1											3
Sa	+	3	17									1						16												2
Sa	+		8									2						6												2
Sa	-	1	14	7								2						5												3
Sa	-	2	3															3												1
Sa	-	3	5	5																										1
K	+	1	14	3														11												2
K	+	2	21															19	1									1		3
K	+	3	11	6														2	3											3
K	-	1	15									1						14												2
K	-	2	12	12																										1
K	-	3	13	8														5												2
Su	+	1	12	8								2																2		3
Su	+	2	13	7														1	2							3				4
Su	+	3	13	10														2										1		3
Su	-	1	7	3														4												2
Su	-	2	13	3														8								2				3
Su	-	3	9	6														3												2

Based on the plot position, the initial data (Table 3.11) indicate that there is a significant difference among top, slope and valley, particularly in the number of spores. The number of spores in the top position was very low, only 41 spores per 50 g of soil, followed by the slope position where the number of spores was 373 and the valley with 657 spores. However, 6 months after tree planting, there was no significant difference, be it in number of species or number of spores per 50 g soil. The number of spores on the top position increased, whereas on the slope and in the valley it decreased. Therefore, 6 months after planting the number of species and spores of mycorrhizal fungi over toposequences tends to be homogeneous, ranging from 94 to 115 spores in 50 g soil sample. At the end of this research period, both the species numbers and the spore numbers per 50 g soil sample had decreased drastically for all four tree species.

3.3.4. Growth of Tree Species in the Experiment Designed by the Farmers

Although all five participating farmers were asked to plant the two different groups of seedlings of each tree species in distinct places, in fact, some of them planted the different groups of seedlings at the same place. Seedlings inoculated and not inoculated with mycorrhizal fungi were planted close to each other, without any boundary or isolation. Cross contamination of mycorrhizal fungi between these two parts of seedlings hence could not be prevented, so mycorrhizae treatment could not be considered as a treatment in the tree growth data analysis.

Tree performance, covering survival, height and diameter growth at five sites of farmers' design experiments 12 months after planting, is shown in Table 3.14. The growth curve of the three tree species in the period of 4 to 12 months can be seen in Fig.3.14.

The performance of mahogany and sungkai (survival, height and diameter growth) was highest at block 2 (Mustarkun's farm), followed by block 4 and 5 (A.Madjid's and Kadir's farms). The lowest growth occurred in blocks 1 and 3 (Sarjuni's and Sumardi's farms). The range was quite wide, around 2 to 7 times for height and diameter growth. For candle nut, the highest growth was shown by plants grown in the block 4 (A.Madjid's farm), followed by block 5 (Kadir's farm) and the lowest one was block 3 (Sumardi's farm). Candle nut was not planted by Sarjuni and Mustarkun. With diameter increment of 0.3 to 0.4 cm and height of 8 to 12 cm per year, growth of the three tree species at Sumardi's farm seems to have been suppressed.

If compared with trees grown in the main research plots, either inoculated or not inoculated with mycorrhizal fungi, the performance of trees in the experiments designed by farmers was much lower, except for survival rates of mahogany and sungkai. The survival of mahogany and sungkai was apparently similar between those two parts of the study. Diameter and height growth of mahogany of the main research at the same period (12 months after planting) were 50 to 100% higher than the growth in this developmental research. Even for candle nut, it was 100% higher, both in diameter and height growth. Sungkai showed similar diameter growth, but height growth in the main research plots was higher too, up to 100%.

Table 3.14. Average survival, height and diameter growth of three tree species at five sites of the experiment designed by farmers, 12 months after planting

Tree species	Blocks/ Farmers	Number of trees	Average survival (%)	Average height growth (cm)	Average diameter growth (cm)
Mahogany	1. Sarjuni	325	91	18.3	0.4
	2. Mustarkun	145	97	94.6	2.0
	3. Sumardi	96	92	9.9	0.3
	4. A.Madjid	226	96	39.3	1.2
	5. Kadir	128	91	40.3	1.0
	Average		94	40.5	1.0
Sungkai	1. Sarjuni	257	88	17.3	0.7
	2. Mustarkun	142	96	99	3.4
	3. Sumardi	93	76	11.5	0.4
	4. A.Madjid	137	93	57	2.2
	5. Kadir	73	92	38.7	1.8
	Average		89	44.8	1.7
Candle nut	1. Sarjuni	-	-	-	-
	2. Mustarkun	-	-	-	-
	3. Sumardi	104	53	8.6	0.4
	4. A.Madjid	176	85	81.7	1.7
	5. Kadir	131	80	39.2	1.2
	Average		73	43.2	1.1

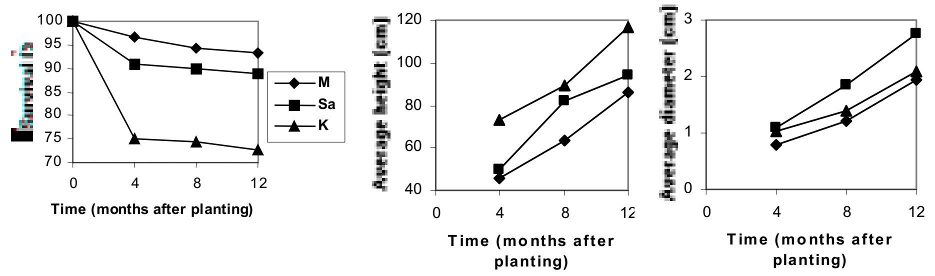


Fig.3.14. Growth of three tree species in the experiment designed by farmers in the period of 4 to 12 months after planting. M=Mahogany, *Swietenia macrophylla*; Sa=Sungkai, *Peronema canescens* and K=Candle nut, *Aleurites moluccana*

Fig.3.14 shows that the survival of candle nut was much lower than that of the other two species, mahogany and sungkai. However, its height growth was highest and its diameter growth was intermediate. Mahogany trees showed the highest survival rates, but their growth was lower than that of both sungkai and candle, either in height or in diameter. Up to 12 months after planting, the mortality of those three tree species seems to continue.

3.4. DISCUSSION

3.4.1. Seedling Growth in the Nursery

Mycorrhizal treatment did not significantly promote growth of seedlings in the nursery. Still, the infection had positively affected seedling growth in general. This advantage is expected to be conserved in seedlings that are transplanted to the field sites. Sieverding (1991) discussed the success of inoculation at the seedbed level, stating that it may not be perceived immediately, but only later after transplanting to the field since mycorrhizae not only improve plant nutrition, but also have other positive effects, e.g. for water uptake as discussed in par.1.1.3 (cf. Oldeman, 1990, p 219).

The effect of mycorrhizal inoculum on Sungkai and Candle nut seedlings is inconsistent. Stem height, shoot and root dry-weight of inoculated seedlings were higher than in those without inoculation. However, the stem diameter was smaller. A smaller diameter causes a lesser sap stream and less mycorrhizal activity, so the stem diameter, shoot and root dry weight are lower too. Higher dry weight of the shoot may be caused by higher stem height, but higher dry weight of roots supposes many mycorrhizae and other micro-organisms to be present in the seedling media. The high population of the micro-organisms consumes much nitrogen and needs many carbohydrates from the phytobionts. As a result, the diameter of the seedlings did not increase.

High populations of micro-organisms present in the seedling media may be caused by composition and condition of the media. The seedling medium was composed of topsoil, livestock manure and sand in a ratio of 3:1:1. The livestock manure used had not matured yet. It was still rather fresh, so that the activity of micro-organisms in the manure was relatively high. Although the medium was pasteurised by means of solarisation, many micro-organisms still survived. By adding inoculum of mycorrhizal fungi to the medium, the overall population of micro-organisms in the medium increased. Rapid development of micro-organisms including mycorrhizal fungi resulted in a sharp increase of the C/N ratio of the medium. The available nitrogen for the seedling growth decreased and therefore growth of the seedlings was slowed down, mainly in seedlings with mycorrhizal treatment. This influence was visually significant shown by candle nut seedlings. Most of the seedling leaves yellowed and fell down.

This hypothesis is supported by shoot-root ratio, particularly in candle nut seedlings. The shoot-root ratio describes the ratio between above- and below-ground biomass of the seedlings. The shoot-root ratio of candle nut seedlings inoculated with mycorrhizal fungi was lower than in seedlings without inoculation. Growth of the below ground part of inoculated seedlings hence is much higher than in seedlings without inoculation, and a part of total mass was micro-organism biomass.

3.4.2. Tree Growth in the Field Sites

Inoculum of mycorrhizal fungi affected the survival of transplanted tree species to the field sites up to 24 months significantly (see Table 3.3). Survival of the four tree species inoculated with mycorrhizal fungi was consistently higher than in plants without inoculation. Symbiosis between mycorrhizal fungi and host plant made the plants healthy and vigorous, so it adapted more easily to unfavourable conditions in the field. Except for his statement on delayed effect of nursery mycorrhizae in the field, Sieverding (1991) also reported that the survival rate of transplanted coffee seedlings to the field sites (an acidic low-P Inceptisol soil), was improved. Even if the VAM inoculum did not improve plant growth in the seedbeds, the survival rate of the seedling in the field consistently improved.

Diameter and height of the stem, however, indicated inconsistent response, except for mahogany. For all observations, both diameter and height growth of the inoculated mahogany trees maintain higher values than in plants without inoculation. On the contrary, diameter and height growth response of sungkai, candle nut and sukun to the mycorrhizal treatment were uncertain over the study period. For instance, the diameter growth of inoculated seedlings of candle nut was higher than in plants without inoculation at 6 and 12 months after planting. Later, at 18 and 24 months, the diameter of inoculated seedlings was lower than in seedlings without inoculation. A similar phenomenon occurred in sungkai and sukun. The average survival, diameter and height growth of each tree species according to the mycorrhizal treatment over the study periods is presented in Appendix 1.

Interaction between bacteria of nitrogen fixing plants and VA mycorrhizae may explain those inconsistent data. Azcon and Mosse *ex* Kapulnik and Douds (2000), stated that the presence of rhizosphere bacteria can stimulate germ-tube growth of VA mycorrhizal fungi. Toro et al. *ex* Kapulnik and Douds (2000) found improved nitrogen and phosphorus accumulation in plants, due to the interaction between *Glomus mosseae* and *Rhizobium*. As explained, the plots where the trees grew were also planted by a legume cover crop, *Pueraria javanica*. This nitrogen-fixing plant was cultivated during the first year of the research period, then it was harvested. During the first year of the tree plantation, the development of mycorrhizae was indeed supported by the abundant *Rhizobium* presence in the rhizosphere, that in turn supported the tree growth. However, after the harvested of the cover crop, the *Rhizobium* population may be decreased and so supports to the VA mycorrhizal fungi decreased, too. In addition, the temperature of the soil increases in absence of the cover crop and this may have reduced the mycorrhizal fungi.

The survival rates of the four tree species on the degraded alang-alang grassland ranged from 69 to 95%, 24 months after planting (Table 3.3). Mahogany, sungkai and candle nut showed stable survival rates from 12 to 24 months. It can be predicted that those three tree species can survive till a mature stage. The first two years are a critical period for most tree species planted on marginal sites. However, sukun mortality seems to continue, mainly if seedlings were not inoculated. Ragone (1997), stated that sukun or breadfruit are grown mainly as backyard trees and, as yet, are not cultivated on a large scale, so data on growth rates of the sukun trees are lacking. Still, sukun trees are an important component of agroforestry systems.

The growth rate pattern of diameter and height in mahogany, sungkai and candle nut over the first two years of their life cycle shows the shape of general growth curves. However, the curves of growth rate of these tree species were slightly lower than the general curve, since the slopes to the x-coordinates were not steeper than the y-coordinates. Backman (1943) *ex* Oldeman (1990, p.87) wrote that generally, growth rate curves should leave the x-coordinate under a stronger angle than returning to it after the maximum. This means the growth rate of mahogany, sungkai and candle nut on degraded alang-alang grasslands were slightly lower than the general growth rate. Nevertheless, compared with the growth rate of mahogany on critical alang-alang grassland in Bojong Lopang, West Java, the growth of mahogany in this study was much higher. The average diameter and height of three years old mahogany in the Bojong Lopang were only 3.2 cm and 161 cm, respectively (Murniati, 1995). Hatta (1999) reported that the mean diameter and height of sungkai of Samarinda (East Kalimantan) provenance at 26 months after planting on degraded *I. cylindrica* grassland were 4.97 cm and 219 cm, respectively. Compared with Hatta's report, the growth of sungkai in this case was also much higher. The growth rate of sukun, both in diameter and height was low as compared to the other species.

Based on tree growth of the four species during early development stages, it can be suggested that mahogany, sungkai and candle nut have a temperament that make them fit to grow on degraded *Imperata cylindrica* grassland, growing vigorously, finding a foothold among the grass and so starting the ecological conversion towards agroforestry.

Alang-alang control methods had no significant effect upon the average survival rates, diameter and height growth of the four tree species, except for the height and diameter growth of the trees 6 months after planting. This means the pressing method, easier and cheaper, leads to a similar tree performance. However, please note that in this study, recovery of the grass was prevented by cultivation of *Pueraria javanica* as a cover crop. It is a vigorously climbing cover crop. It replaced the emerged young shoots of the grass perfectly, so it replaced the old alang-alang ecosystem component by a new one for the agroforestry ecosystem. Therefore, the pressing method can be implemented in converting of alang-alang grassland into tree plantations or agroforestry, as the tree performances were not significantly lower than the other methods (spraying and ploughing). In addition, this method should be combined with a cover crop.

As the three blocks of the study site are heterogeneous in site quality, the tree performance varied, too. Most variations among the blocks were higher than the variations among the treatments. These were shown in particular by diameter and height growth from 12 to 24 months after planting. Following the site quality, where the first block was most hospitable for tree growing (rich), followed by the third block (moderate) and finally the second block (poor); the tree performance in the first block was maximal, followed by the third block (moderate) and the second block came last (poor). Both diameter and height growth of the four tree species in the first block were higher than in the second block by nearly 100%.

Generally, tree growth in the main study, the experiment designed by the researcher, was higher than the tree growth in the experiment designed by farmers. It varied from 50 to 100% (except for tree survival and diameter of sukun trees). The possible causes are poor soil nutrients and poor physical properties of the soil, particularly in the first and third block, where the texture of the soil consisted of 66 to 77% of sand (see Table 2.7). All five participating farmers did plant no cover crop as a first effort to adjust the soil fertility. They planted non-nitrogen fixing annual food crops, except A. Madjid, a participating farmer, who planted groundnut in the small part of his farm.

3.4.3. Shading Capacity

Relative shading, leaf area index and crown surface of candle nut trees were higher than in the other three tree species. As to its shading capacity, required for reducing alang-alang grass, this species showed an optimal capacity. Sungkai trees, indeed, also have an appropriate shading capacity to suppress the grass. However, during long periods of drought this species sheds its leaves and twigs to survive. So, during that period the shading capacity of the trees drastically drops.

3.4.4. Dynamics of Mycorrhizal Fungi

Spore numbers of VA mycorrhizal fungi were significantly different over toposequences (top/slope/valley) before agroforestry plots were established. This condition changed 6 months later. This is probably caused by an improved and homogeneous microclimate over the area. By planting trees and a legume cover crop soil temperature on the top part of the plot was reduced, allowing the mycorrhizal fungi to survive and to produce more spores. However, in the valley below, the number of spores decreased drastically. This phenomenon can be explained by the seasons. As the first soil samples were collected during the dry season, and six months later sampling was done within the rainy season. According to Setiadi, 2000 (pers. comm.), mycorrhizal fungi produce abundant spores during stress conditions (drought and heat) and they produce less spores but abundant mycelia during the rainy season, making the soil environment more hospitable.

In general, both the number of species and spores of mycorrhizal fungi decreased over the two years of the study period. Decrease in spore numbers can be explained by the seasonal influences, mentioned above. The initial observation was done during the dry season, while the second (6 months after planting) and the third observation (24 months after planting) were carried out within the rainy season. However, a decreasing number of species is a contradictory phenomenon. Increasing biodiversity of plants (phytobionts) should be followed by increasing biodiversity of mycorrhizal species, too. Interactions between native or local species and inoculated species may have contributed to the inverse phenomenon. This finding, however, is in a line with Setiadi's (1999) report, where spore types of *Glomus* in agroforestry sites was six times lower than in alang-alang sites.

Initially, there were 14 species of VA mycorrhizal present in the plots. Species no.1 and 9 occur abundantly and other species (no 2, 3, 4, 5, 6, 7, 8, 10,11, 12,13 and 18) occur sometimes to frequently. Four species of VA mycorrhizae (resting spores in the Mycofer) were inoculated by means of planting inoculated seedlings in certain places of the plots. The fungi were *Glomus manihotis*, *Glomus etunicatum*, *Gigaspora rosea* and *Acaulospora tuberculata*. Six months after planting of the inoculated seedlings, the diversity of VA mycorrhizal species was transformed because of a slightly different species composition. Species no 1, 6, 14, 19 and 24 were abundant during that period. Observation 24 months after planting the inoculated trees showed that, the species composition of VA mycorrhizal fungi in the plots was transformed again, where species no.1 and 15 being abundant and species no. 9 and 16 occur only sometimes to frequently. These transformations of composition in the species VA mycorrhizal fungi indicated that species no.1 (*Glomus* sp., black), no.6 (*Glomus* sp., reddish-brown) and no.9 (*Glomus* sp., yellow) were aggressive species in the area.

None of the four species of inoculated VA mycorrhizal fungi appeared in the soil samples six months after planting of the inoculated seedlings. It was supposed that those species were dormant during that period, since two of the species showed up again at 24 months after tree planting. One species (no. 15, *Glomus etunicatum*) was abundant and another one (species no.16, *Glomus manihotis*) was rare.

3.5. CONCLUSIONS

Within this experiment, we can distinguish three steps of interactions between trees and mycorrhizal fungi: the nursery phase, the phase of transplantation to the field sites and early tree growth in the fields, and the phase of subsequent growth of the trees that survived in the critical early growth stage. In the nursery phase, inoculation of mycorrhizal fungi did not promote seedling growth. During transplanting and early tree growth in the field, mycorrhizae associations have to be formed to survive under much poorer soil conditions. Although the soil has an abundance of mycorrhizal spores of considerable diversity, the nursery stage inoculation leads to a significant increase in survival rate. However, the average increase in survival of the four tree species was only 6.5%. The effect appeared to be largest in an absolute sense in sukun, the tree with the lowest survival rate, where survival increased up to 15%. The nursery-stage inoculation of the trees did not have any positive effect on the subsequent growth of the trees that survived during the critical early stage. Our data do not indicate a compelling need for the use of the inoculum of the type used in the nursery stage unless the inoculum is readily available at very low cost. However, the increase in average survival by 6.5% may be relevant for specific situations.

Glomus sp., black; *Glomus* sp., reddish-brown and *Glomus* sp., yellow were aggressive indigenous species of VA mycorrhizal fungi in the study sites, whereas *Glomus etunicatum* is a strong and adaptable species to the sites, introduced by inoculation of seedlings.

Based on performance of selected tree species growing in the degraded alang-alang grassland and their capability to replace the grass, mahogany, sungkai and candle nut are most suitable to be planted in those degraded lands. Breadfruit (sukun) clearly had the lowest survival rate, as well as the slowest growth of the surviving trees. This tree species may therefore be considered unsuitable for the harsh conditions of *I. cylindrica* grasslands.

Tree performances under the method of pressing of *I. cylindrica* by a heavy log were not lower than the other methods (spraying with herbicide and ploughing or hoeing). This simplest method, may therefore be recommended for further use. However, all methods should be followed by planting of a legume cover crop.

4. CONVERSION OF AN ALANG-ALANG GRASSLAND ECOSYSTEM INTO AN AGROFORESTRY ECOSYSTEM

4.1. INTRODUCTION

As explained in chapter 1, ecologically an *Imperata cylindrica* (alang-alang) vegetation is a blocked development phase in the ecosystem development. A blocked ecosystem or a blocked phase is a phase that inhibits or at least slows down the processes leading to the next development phase. Natural succession on abandoned fields needs decades to build a new high biodiversity ecosystem such as secondary forest and even primary forest (e.g. Vester, 1997). An alang-alang phase can postpone this complex process by many years. Breaking open the alang-alang ecosystem to build a new productive and sustainable ecosystem needs human intervention. Any development phase that can replace the alang-alang ecosystem should allow increasingly complex interactions among the components. As said, these components have to be introduced into the blocked alang-alang ecosystem by methods like planting trees, nitrogen-fixing cover crops and/or annual food crops.

Planting several species of tree seedlings inoculated with mycorrhizal fungi or relying on the existing inoculum potential on degraded alang-alang grassland, in combination with a nitrogen-fixing cover crop as discussed in previous chapters, indeed initiates a process of ecosystem conversion. Both mycorrhizal inoculation and alang-alang suppression are considered as interdependent forces driving the conversion of an alang-alang ecosystem towards an agroforestry ecosystem. The nitrogen-fixing soil microflora is a third factor, enhanced by planting leguminous cover crops. The shift in microclimate caused by shading, due to the leaf canopy of trees and legumes, is a fourth factor. It reduces alang-alang vitality. The experimental plantations described in the present chapter address these four interacting factors and their significance in the ecological conversion, the subject of the present thesis.

Prior to this conversion process, several methods of alang-alang control to reduce the above-ground biomass of the grass should be implemented. So, a fast new development phase can be accomplished and the risk of fire can be reduced. Temperament and characteristics of the four selected tree species as well as their capability to grow in degraded alang-alang grassland have been discussed in chapter 3. In the present chapter attention is focussed on the reduction of the grass itself, the contribution of the cover crop, *Pueraria javanica*, in the conversion process, the changes of land cover, the growth and production of annual food crops, as well as the farmer’s participation in the process.

De Foresta and Michon (1997) discussed the transition from *I. cylindrica* grassland into agroforest, where two basic requirements can be achieved at the same time by planting a combination of cash crops belonging to different parts of the successional spectrum, along with the agroforestry tree species.

(1) Throughout the establishment process, from planting to the productive phase of the trees, local communities should get as much income and food for household consumption as possible
(2) In order to reduce the maintenance cost to a minimum, the establishment process should as far as possible follow the ecological rules of plant succession.

The authors described the different designs of the transition process that can be adapted to the different conditions of the alang-alang areas as well as to the socio-economic conditions of the local farmers. If huge areas of grassland are available for conversion by a limited number of people, more extensive systems are highly desirable since the transition process should be accomplished as fast as possible in order to limit the high-risk period of fire. In this condition, farmers preferably choose early-producing tree crops, like rubber or in our study, candle nut or fruit trees.

Growing food crops in between rows of newly planted trees is a well-established practice in the ‘taungya’ system, adopted widely in Java. In the traditional implementation, however, the trees belong to the state forest managers and only the benefits of the food crops accrue to the smallholder farmers. Van Noordwijk and Tomich (1995) commented on the unbalance of this system where competition between trees and crops leads to intrinsically different management objectives between smallholder and state forest managers. If the trees belong to the farmer, however, some level of competition can be tolerated as it will not affect the total value of the system based on a trade-off between yield of the food crop and future yield of tree products. Growing food crops in between the trees may in fact be rewarded by better early growth of the trees, compared to a pure tree stand. Bagnall-Oakeley et al. (1997) commented on the problem that *I. cylindrica* may re-establish at the stage where light levels in the inter-row are too low for light-demanding food crops, while not being low enough to control *I. cylindrica*. Purnomosidhi et al. (in press.) indicated that the light level in the inter-row has to be reduced to less than 20% of full sunlight to control *I. cylindrica*.

Herbaceous cover crops belonging to the genus *Pueraria* have been shown to reduce the growth of *I. cylindrica* effectively. They can be used to prevent and in some cases to eradicate the grass (Macdicken et al., 1997). In the conversion of alang-alang grassland into an agroforestry system, legume cover crops have a multiple functionality. They cast shade reducing grass vitality and in the same time contribute to the upgrading of the poor fertility in almost completely degraded tropical soils. In addition, they establish a favourable microclimate as well, and so enhance the activity of microflora and -fauna.

Pueraria javanica Benth. is native to the mainland southeast Asia, Malaysia and Indonesia and is now widespread throughout the wet tropics (Macdicken et al., 1997). Synonyms are *Pueraria phaseoloides* (Roxb.) Benth., *P. phaseoloides* var. *javanica* (Benth.) Hook. Common names are Puero (Australia), tropical kudzu (most of the tropics), kacang ruji (Java, Indonesia). *P. javanica* has vigorous twining and climbing stems. It is a hairy perennial and is one of the best tropical legumes for smothering weeds (Skerman, 1977). It was deep-rooted on acid soil in Nigeria and Indonesia (Hairiah and van Noordwijk, 1987). On an acid soil in Onne, Nigeria, it produced 2.2 Mg ha^{-1} dry matter, with a total N content of 60 kg ha^{-1}, 14 weeks after planting (Hairiah and van Noordwijk, 1986). The direct N benefits from a well-developed leguminous cover-crop for a sub-sequent crop have been calculated by many authors, and are often equivalent to 50 to 100 kg N ha^{-1} applied in the form of commercial fertiliser (Hairiah and van Noordwijk, 1989).

In Indonesia, rehabilitation of alang-alang grasslands or their transition to more productive agro-ecosystem, has a high priority at all Indonesian Government levels. Several programmes were implemented on state forestland as well as outside this domain, such as for a private forest; community forestry; demonstration plots for natural resources conservation (UP-UPSA), demonstration plots for permanent agriculture (UP-UPM), etc. Most of the programmes use agroforestry technologies. However, so far, experiences showed that the programme was not sustainable, since the farmers involved did not see clear benefits emanating from their efforts and/or 'feel a genuine desire' to nurture and protect the trees. Potter (1997) argued that agroforestry interventions on the evolution of the grasslands that do not start from the farmers' point of view are essentially a waste of time.

Smallholder farmers with secure tenure status are probably the most effective and efficient in converting alang-alang grasslands into more productive land (Purnomosidhi et al., in press.). Local people should act as a subject in the program that aims to rationalise and empower their life. Active participation by local people can be achieved when they are involved actively, both in planning and in executing the program. Nasikum *ex* Suharti (2000), claimed that the concept of community participation is not fully satisfied by "just" receiving the people's contribution in the form of labour, in kind or, in cash. Participation must contain the element of initiative and determination, emanating from the community itself. When community contributions do not comprise such bottom-up elements, the concept changes from participation into mobilisation. The concept implies that people's participation must be preceded by the build–up of a participatory environment.

The scientific questions raised in this chapter are:

1. Which methods of the *I. cylindrica* management are optimally suited to assist the conversion of the alang-alang ecosystem into an agroforestry ecosystem?
2. Is *P. javanica*, as a cover crop, able to prevent the recovery of alang-alang grass, and does it dominate the land cover after one year?
3. In how far do the shading capacity and LAI of trees influence the yield of annual food crops in inter-cropping systems?
4. Is there an improvement of the soil fertility after two years of agroforestry system establishment on the alang-alang lands?
5. How do local farmers perceive the technical merits of the agroforestry systems tested and are they interested in applying this, with modifications, on their own farms?

4.2. MATERIAL AND METHODS

4.2.1. Site Identification

An agroforestry system was established on degraded *I. cylindrica* (alang-alang) grasslands. The system was tested in three separated places. The grasslands were private property in the Semoi II and Semoi III villages. Therefore, the participation of the local society in converting such degraded land into more productive land is important. As mentioned before, the research sites are located inside a transmigration area, at a distance of 20 to 27 km North-West of Wanariset I Research Station (Location of the MOF-Tropenbos Kalimantan Programme), East Kalimantan, Indonesia (see par.2.1 and 2.5, and Fig. 2.1 for details). In all three blocks, alang-alang was the dominant vegetation.

Before the plots were established, a vegetation analysis was done in the sites by using a systematic random sampling with 216 sample units (72 sample units per block). Their size was 50 cm x 50 cm each (see par.4.2.3 for a detailed method of the analysis). The average alang-alang population density was 403; 413 and 519 stems m^{-2} for the first, second and third blocks, respectively. Biomass dry-weight of the grass in block I, II and III was 477; 179 and 899 g m^{-2} respectively. The average biomass per stem amounted to 1.18; 0.43 and 1.73 g per respective block and reflects the height of the grass. Soil fertility of all three blocks was very low to low, according to the pH, N, P, K and C organic content. As shown in Table 2.5 the average pH (1N KCl) ranged between 4.9 and 5.4., which were classified as acid soils according to soil fertility classification of PPT (1997). The nitrogen and phosphorus contents are very low, i.e. 0.06 to 0.09 % for nitrogen and 4.4 to 9.9 mg kg^{-1} for phosphorus. The potassium and $C_{organic}$ content are low, ranged from 0.19 to 0.27 $cmol_e$ kg^{-1} for potassium and 1.41 to 1.62 % for C organic. Soil texture varied from clay loam, sandy clay and sandy clay loam to sandy loam. The topography varied among the blocks. Block I and block II lie on flat to gently slopes with a gradient from 3% to 25%, except in a small part of the second block where the slopes up to 55%. Block III is undulating to mountainous with steep slopes, varying between 8% and 55%.

4.2.2. Agroforestry Plot Establishment

The agroforestry plots were established by planting trees and crops, after preparation by localization of the plots in the field, contour map drawing, *I. cylindrica* treatments, establishing fire breaks and planting live fences.

Three methods of alang-alang management were applied, i.e. spraying with herbicide (H), ploughing or hoeing (Pl) and pressing with a heavy log (Pr). The herbicide used was Glyphosate (Polaris) with a dosage of 8 L/800 L water ha^{-1}. Spraying alang-alang grass by herbicide was done one month before planting the trees. Hoeing and pressing treatments were implemented one week before planting the trees. To protect the plots from fire, firebreaks were put into place by clearing strips of land of 5 m wide, surrounding each plot. A living fence was grown to secure the plots from domestic animals as well as wild-pig attacks. It consisted of

Gliricidia sepium (Leguminosae-Fabaceae) which was planted densely around the plots by means of stem cuttings.

Based on our initial assessment of farmers' preference and likely suitability, the following tree species were used: mahogany (*Swietenia macrophylla* King, Meliaceae) **(M)**, sungkai (*Peronema canescens* Jack., Verbenaceae) **(Sa)**, candle nut (*Aleurites moluccana* (L.) Willd., Euphorbiaceae) **(K)** and sukun (*Artocarpus altilis* Fosberg. Moraceae) **(Su)**. The experimental design, plot localisation in the field and lay out of the plots can be seen in par. 2.5 and 3.2.2. A legume cover crop was planted in all subplots as an initial effort to improve soil fertility and micro-life as well as to prevent recovery of the alang-alang grass. The cover crop was *Pueraria javanica* (Leguminosae – Fabaceae). It is a spreading and climbing plant. It was directly sown at 50 cm x 50 cm. Some seeds of the cover crop were put in each hole made with a dibble stick. Then, the holes were closed with soil from their surroundings. The cover crop was planted at the same time as the trees and it was cultivated during the first year of the research period. Food crops were planted after the cover crop was harvested, by the participating farmers, who are the owners of the land. In this collaboration, the farmers provided the necessary labour to cultivate the crops and the project supplied the production materials, such as crop seeds and fertilisers.

Beside those three agroforestry plots established as the main research, designed and managed by the researcher, there were 5 other agroforestry plots as a development research, established in parallel based on farmers' design. The additional plots were established on farmer's grassland by means of full farmers' participation. Each plot sized 0.5 ha, was managed by one participating farmer, so there were five farmers involved in the program. The project gave out the tree seedling and let the farmers decide what and how to do with it. As additional support, each farmer was given a certain amount of money to cover the cost of first land preparation, Rp. 250.000,- (ca US $ 25) each. The researchers' role in these trials was confined to monitoring the growth of the trees and discussions with the farmers to understand their management decisions.

4.2.3. Data Collection

Several parameters were observed to assess the success of the agroforestry plot establishment in the degraded alang-alang grasslands. Those parameters cover tree growth, reduction of population and aboveground biomass of *I. cylindrica*, relative land cover and undergrowth species, the cover crop (*P. javanica*) biomass and nutrient contents, food crops yields, the improvement of soil fertility and farmers' participation. The tree growth parameters were presented in chapter 3. The other parameters will be discussed in the present chapter.

Imperata cylindrica *population and above-ground biomass*

Population and aboveground biomass of *I. cylindrica* were observed four times; before and six months after treatment, after harvesting of the cover crop (12 months) and at the end of the research period (24 months). Samples were taken systematically, in three places per subplot, size 50 cm x 50 cm. For all three blocks, there were 3x2x4x3x3=216 samples of alang-alang. All stems of *I. cylindrica* found in the sample area were counted and their dry-weight was obtained by drying the grass in an oven at a temperature of 70°C within 12 hours.

Relative land cover

Land cover and undergrowth species were observed six months after tree planting and after harvesting the cover crop (12 months). Land cover was recorded as 100 % when the surface in a certain sub-plot was fully covered by vegetation. The value ranges between 0 to 100%. The land cover of each sub-plot was determined according to the undergrowth species, which cover the land of the sub-plot, as an ecological indicator, so land cover percentage here uniquely concerns those species. The undergrowth species were classified into four groups, namely *I. cylindrica* (I.c), *P. javanica* (P.j), *Pteridium aquilinum* (P.a) and a group including diverse other species (others). Relative land cover at each sub-plot was estimated based on the ratio of land cover by certain species to the total surface of the sub-plot.

Cover crop biomass and nutrient content

The cover crop *P. javanica* was harvested in October 2000 when it was one year old. Before harvesting all the biomass, some samples were collected by following a systematic sampling method. Samples, sized 50 cm x 50 cm, were taken in three places in each sub plot. Each sample consists of two parts; "biomass" and "standing brown litter" or "necromass". The biomass sample refers to the green parts of the plant (stems and leaves), and so called as greenmass, whereas "the standing brown litter sample" refers to all dead plant material on the topsoil. The term "necromass" is used here for short. All samples, totalling 3x2x4x3x3=216 samples of biomass and also 216 samples of necromass, were dried in an oven at a temperature of 70°C during 12 hours in order to determine their dry weight. Besides, some samples of the biomass were collected and transported to the Biotrop Soil Laboratory, in Bogor to be analysed as to nutrients content, particularly nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg). Concentration of N was determined by means of the Kjeldahl method, while P, K, Ca and Mg were calculated by total extraction in concentrated (H_2SO_4). The concentration of elements in the necromass is assumed to be the same as those of the biomass, since necromass samples were not analysed. In this way, the contribution of the cover crop to the production and mobilisation of additional nutrients improving soil fertility was estimated.

Annual food crops

Soon after harvesting the cover crop *P. javanica*, the research plots were cultivated with annual food crops in an inter-cropping system (*tumpangsari*). The first block was cultivated with corn (*Zea mays*), the second block with mung bean (*Vigna radiata*), and the third block with mung bean (in the main plot of [-], tree seedlings not inoculated with mycorrhizal fungi), and with corn and ginger (*Zingiber officinale*) in the main plot of [+] (tree seedlings inoculated with mycorrhizal fungi). The owners of the plots cultivated these themselves according to the plans of the project, and with seeds, fertiliser and pesticides provided by the project. However, this was not done in all sub-plots, due to differences in perception among the participating farmers. In the first block, *tumpangsari* was carried out in all sub plots. In the second block, *tumpangsari* was only applied in 14 sub-plots, 9 sub-plots in the main plot of [+] (tree seedlings inoculated with mycorrhizal fungi) and 5 sub-plots in the main plot of [-] (tree seedlings not inoculated with mycorrhizal fungi). The other 10 sub-plots were not cultivated with an annual food crop because the land was still dominated by alang-alang i.e. sub-plots KPr, MPr and KH in the main plot of [-], and SaPr, KPr, MPr, SaPl, SuPl, KH and MH in the main plot of [+] (see Fig.2.2 and 2.4). In the third block, the *tumpangsar*i was only applied in 8 sub-plots in the main plot of [-] and at all 12 sub-plots in the main plot of [+]. These farmers' decisions on where they judged inter-cropping to be worthwhile and where not complicate the attribution of any differences in tree performance in these plots to specific 'treatments'.

*Inter-cropping with corn (**Zea mays**)*

As explained previously, corn was used as inter-crop in the first and third block. In the first block, the inter-cropping system was set-up by using a split-plot experimental design.

The main plots are weeding treatments:

- Weeding (W1)
- Not weeding (W2)

The sub plots are tree species (as main crops):

- Mahogany (M)
- Sungkai (Sa)
- Candle nut (K)
- Sukun (Su)

The sub-sub plots are fertiliser treatments:

- Fertilised (F1)
- Not fertilised (F2)

Each sub-sub-plots as an experimental unit was set up three times. Therefore, there are 48 experimental units of 4 x 16 m^2 each.

Chicken manure as organic fertiliser was applied before planting the corn with a dosage of 2 Mg ha^{-1}. It was put into the planting holes and left for two weeks. Later, corn seeds were sown in the holes and covered by soil from around the holes. Three weeks after planting the corn plots were weeded. An inorganic fertiliser i.e. (15-15-15) NPK compound fertiliser was used as an addition and was applied one day after weeding with a dosage of 100 kg ha^{-1}. Corn yield was determined as the fresh weight and as the dry weight of the grain. The fresh weight was determined soon after harvesting including the corn's cobs. Then, the fresh corn was dried by solarisation until the water content was about 20% (air dry). Later, the corn seeds were separated from the cobs and weighed. This value is called "grain dry weight" of the corn.

In the third block, particularly in the main plot of [+], the inter-cropping with corn was carried out twice. The first cycle in the season is from April to July 2001, and the second in the season from September to December 2001. The corn cultivated in the first season was divided into two parts, one part fertilised, the other not so. The fertiliser used was only organic manure with a dosage of 2 Mg ha^{-1}. All plots were weeded. For the second season, all plots were fertilised and weeded, since the farmer was not willing to apply fertiliser only to half of the plants. In this second season, the fertiliser used was a combination of organic (livestock manure) and in-organic fertilisers. In-organic fertilisers used were Urea with a dosage of 150 kg ha^{-1}, 46% N content and TSP with a dosage of 75 kg ha^{-1}, 46% P content.

Intercropping with mung bean (Vigna radiata)

Inter-cropping (*tumpang sari*) with mung bean in the second block took place only in 14 sub-plots. All plots were fertilised, since the farmers did not want to apply fertiliser partially, skipping some plants. All planted sub-plots were also weeded. Inter-cropping with mung bean was also carried out in the third block, especially in some sub-plots in the main plot of [-]. All plants were fertilised and weeded.

Dynamics of the soil fertility

After 24 months, several composite soil samples were collected from the agroforestry plots according to the blocks and soil map units (see par. 2.5.4) in order to determine the chemical soil properties. These soil samples were transported to Bogor and analysed by the Biotrop Soil Laboratory. Several undisturbed soil samples were also collected to determine the physical soil properties. This analysis was carried out by the Soil Laboratory, Faculty of Forestry, Mulawarman University.

Farmers' participation and local people's opinions

Farmers' participation was assessed by means of daily interactions among them and the researchers, and by their activities in the project. The farmers were classified into two groups. The first one contained three farmers, who were involved in the three blocks of 'the main research'. They were the owners of the lands in the respective blocks. The second group included five farmers, involved in the five blocks of 'the development research'. Opinions of the local people concerning the project were assessed by bringing them to the plots and letting them sow around the plots. This activity was conducted two times, the first was 6 months after trees and cover crop planting and the second was 24 months after the agroforestry plots were established. After these field visits, a short discussion and interview were conducted with every visitor. The total number of visitors was 45. They were divided into three groups, each group containing 15 persons and they visited one block of the agroforestry system.

4.2.4. Data Analyses

The average value of each parameter of each sub plot was used as inputs in the statistical analysis using General Statistics (Genstat) 5 release 3.2 software. Significant F-values established by Anova were further examined by comparisons of means according to the Duncan's Multiple Range Test (DMRT) or by specified contrasts. Graphical data such as land cover, dynamics of soil fertility and farmer participation as well as opinions and perceptions by local people were described and discussed.

4.3. RESULTS

4.3.1. *Imperata cylindrica* Population and Biomass

Twelve months after treatment, the *I. cylindrica* population and biomass declined dramatically. Some sub-plots, especially in the first block, even attained a value of zero, for both population and dry weight of the biomass. However, in some other sub-plots, mainly in the second block, the values were still high, about 50 % of the initial value. Then, when the cover crop had been harvested, the alang-alang grass started recovering. The recovery of the grass in the first and third blocks could be prevented by means of an inter-cropping system. In the second block, however, the grass reappeared more abundantly than in the initial condition. The effects of grass management (spraying, ploughing and pressing) in reducing the above-ground biomass of the grass are presented in Table 4.1.

The dry weight of the *I. cylindrica* biomass decreased dramatically 6 months after treatment, mainly when the spraying method was followed. The reduction of the grass biomass after ploughing or pressing was about equal and both are less efficient than the spraying treatment. Apparently, the dry weight of the biomass continued to decline. Twelve months after treatment, the spraying and ploughing methods led to the same reduction of the biomass dry weight. The pressing method lagged behind.

In the period of 12 to 18 months after treatment, annual food crops were intercropped in all three plots (*tumpangsari*), e.g. corn (*Zea mays*), mung bean (*Vigna radiata*), and ginger (*Zingiber officinale*). There was no observation of *I. cylindrica* biomass during this period, since weeding had taken place. Then, in the period of 18 to 24 months, there was a long dry season in the research sites, so that no food crops were cultivated during this time, except in half of the third block (at the main plot of [+]).

At the end of the period of observation (24 months after planting), the biomass of *I. cylindrica* looks similar for all treatments. However, when separated based on the blocks, the biomass of alang-alang was highest in the second block, followed by the first block and lowest in the third blocks. This is a reversal of the initial conditions, when the second block had the lowest above-ground biomass of the grass as the plot had been burnt 3 months before the agroforestry plot was established.

Table 4.1. Effects of *I. cylindrica* management on reducing the dry weight of the grass biomass, under four tree species, 6, 12 and 24 months after the treatments. Values followed by different letters in the same column are significantly different ($P < 0.05$) according to Duncan's Multiple Range Test (DMRT), NS=no significant difference ($P > 0.05$). Initial biomass dry weight of *I. cylindrica* is used as covariate.

Treatments/Blocks	Initial dry-weight of biomass (g 0.25 m^{-2})	Biomass dry-weight reduction (g 0.25 m^{-2})		
		6 months	12 months	24 months
Tree species				
Mahogany (M)	134.4	98.7^{NS}	114.3^{NS}	94.8^{NS}
Sungkai (Sa)	158.2	97.5	112.7	96.3
Candle nut (K)	111.0	97.1	106.0	101.9
Sukun (Su)	114.5	98.0	108.2	99.2
I. cylindrica **management**				
Herbicide (H)	116.0	114.7^{a}	115.4^{a}	103.9^{a}
Ploughing (Pl)	133.8	91.0^{b}	115.7^{a}	97.4^{ab}
Pressing (Pr)	138.8	87.7^{b}	99.3^{b}	92.9^{b}
Blocks				
First (I)	119.3	73.1	114.8	80.6
Second (II)	44.6	13.8	22.6	-1.7
Third (III)	224.6	206.6	201.8	215.3

Different tree species did not lead to significant differences in the reduction of dry weight of the grass biomass, while the spraying caused the highest reduction. It was different from the pressing method for all observed cases, and had results similar to ploughing after 12 and 24 months.

The reduction of the biomass dry weight was clearly different among the blocks. The third block has the highest reduction rate for the biomass dry weight, the lowest one having been found in the second block.

4.3.2. Relative Land Cover

Land cover in this paragraph refers to land covered by non-woody species, i.e. *I. cylindrica*, the cover crop *Pueraria javanica*, the fern *Pteridium aquilinum*, and other herbaceous weeds 6 and 12 months after reduction of *I. cylindrica*. Other low weeds such as *Chromolaena odorata*, *Melastoma malabathrica*, *Blumea* sp., *Mikania* sp., had the opportunity to grow since the land was completely opened soon after the *I. cylindrica* suppression. Ferns, present in the second plot also showed a strong development.

Twelve months after treatment of the grass or after planting of the cover crop, most of the land was covered by the cover crop. However, some sub-plots were still dominated by *alang-alang*, mainly in the second block. The mean values of relative land cover were calculated per sub-plot and per kind of *I. cylindrica* treatment in the first, second and third blocks, 6 and 12 months after treatment (Figs. 4.1 and 4.2).

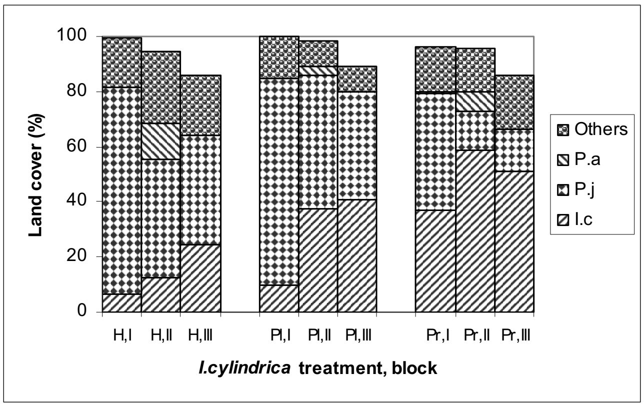


Fig.4.1. Land cover by various undergrowth species, 6 months after *I.cylindrica* reduction. H=herbicide, Pl=ploughing, Pr=pressing. *I.c=I.cylindrica*, P.j=*Pueraria javanica,* P.a=*Pteridium aquilinum*, Others=others species (*Chromolaena odorata*, *Melastoma malabathrica*, *Blumea* sp., *Mikania* sp.); I, II and III = first, second and third blocks.

Figure 4.1 shows that 6 months after planting the cover crop *P. javanica* started to spread and covered nearly 50 % of the land of each sub plot, except at some sub plots with the pressing treatment of alang-alang in the blocks II and III. In those sub plots, *I.cylindrica* still dominated the ground surface. In this period, most of the land surfaces were not completely covered by those vegetation types yet, except in the first block after herbicide and ploughing treatments that reached 100% land cover. Certain land surfaces remained bare.

When the cover crops reached the age of 12 months, they dominated and covered almost 100% of the sub plot surface in the first block (Figs.4.2 and Plate 4.1). In the second block, the cover crops occupied around 70% of the land surface, except at sub plots where the alang-alang grass had been pressed. Here, alang-alang was still dominant and ferns were frequent. As shown in Fig. 4.2, the *P. javanica* covered about 75% of the total surfaces in plot three after both herbicide application and ploughing. Under pressing, it only occupied 48% of the total land surface. Alang-alang still dominated in some sub-plots treated by pressing in the second and third blocks. In those sub-plots, it seems that the cover crop needs more time to outshade the alang-alang.

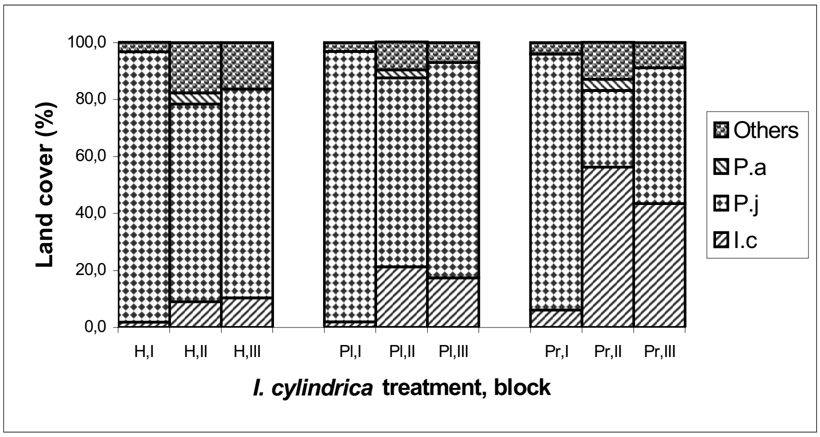


Fig.4.2 Land cover by various undergrowth species, 12 months after *I.cylindrica* treatment. H=herbicide, Pl=ploughing, Pr=pressing. *I.c=I.cylindrica*, P.j=*Pueraria javanica,* P.a=*Pteridium aquilinum*, Others=others species (*Chromolaena odorata*, *Melastoma malabathrica*, *Blumea* sp., *Mikania* sp.); I, II, III = first, second and third blocks.

4.3.3. Cover Crop Biomass and Nutrient Contents

The average dry weight of the biomass and the necromass samples per 0.25 m^2 is presented in the Figure 4.3 and the effect of alang-alang management on the dry weight of the biomass and necromass of the cover crop can be seen in Table 4.2.

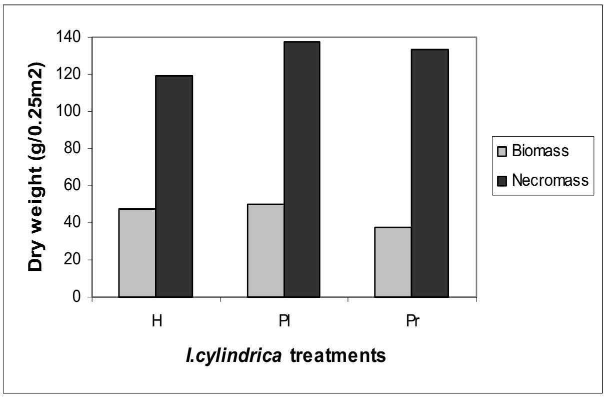


Fig.4.3. Dry weight of the cover crop biomass and necromass, one year after planting under three kinds of *I.cylindrica* treatment (H=herbicide, Pl=ploughing and Pr=pressing)

Table 4.2. Effect of *I. cylindrica* management on the dry weight of the biomass and the necromass of the cover crop under the four tree species. M=Mahogany, *Swietenia macrophylla*, Sa=Sungkai, *Peronema canescens*, K=Candle nut, *Aleurites moluccana* and Su=Sukun, *Artocarpus altilis*; H=herbicide, Pl=ploughing and Pr=pressing. Values followed by different letters in the same column are significantly different (*P< 0.05*) according to Duncan's Multiple Range Test (DMRT), NS=no significant difference (*P> 0.05*)

Treatments/Blocks	Dry-weight of cover crop (g 0.25 m^{-2})	
	biomass	Necromass
Tree species		
Mahogany (M)	45.9^{NS}	121.7^{NS}
Sungkai (Sa)	47.0	143.3
Candle nut (K)	42.3	125.7
Sukun (Su)	45.0	130.2
I. cylindrica **management**		
Herbicide (H)	47.5^{a}	119.4^{NS}
Ploughing (Pl)	49.9^{a}	137.6
Pressing (Pr)	37.8^{b}	133.7
Blocks		
First (I)	60.3	181.9
Second (II)	34.6	80.0
Third (III)	40.3	128.8

Fig. 4.3 shows that the dry weight of the cover crop biomass after ploughing is higher than after either herbicide application or pressing. The pressing method resulted in the lowest values. The dry weight of the necromass of the cover crop after ploughing is also the highest one, followed by pressing. Herbicide treatment showed the lowest values. The dry weight of the necromass was nearly three times that of the biomass dry weight.

Table 4.2 shows that the biomass dry-weight of the cover crop was significantly different among the alang-alang treatments, whereas necromass dry weight was not. In addition, the differences in dry weight of both parameters were clearly significant among the three blocks.

The grand average of the biomass and necromass of the cover crop were 45 g 0.25 m^{-2} and 130 g 0.25 m^{-2}, respectively. These mean that the average amounts produced were 1.8 Mg ha^{-1} for the biomass and 5.2 Mg ha^{-1} for the necromass. In total they were 7 Mg ha^{-1}.

The nutrient content of the cover crop biomass and necromass is based on the results of the biomass sample analysis shown in Table 4.3.

Table 4.3. Average nutrient content of the cover crop biomass and necromass, one year after planting. * = the concentration of elements in the necromass is assumed to be the same as those of the biomass

	Concentration of elements (%)					Nutrient contents (kg ha^{-1})				
Items	N	P	K	Ca	Mg	N	P	K	Ca	Mg
Biomass (Stems)	1.14	0.10	1.19	0.17	0.27	12.4	1.1	12.9	1.8	2.9
Biomass (leaves)	2.74	0.26	1.99	0.21	0.33	19.7	1.9	14.3	1.5	2.4
Total (biomass)	1.94	0.18	1.59	0.19	0.30	32.1	2.0	27.2	3.3	5.3
Necromass	-	-	-	-	-	101.1*	9.4*	82.8*	9.9*	15.6*
Total	-	-	-	-	-	133.2	11.4	110.0	13.2	20.9

Table 4.3 suggests that the cover crop *P. javanica* has an important role in improving the soil fertility, especially by supplying some amount of nutrients. Totally, it can enrich the soil by 133 kg Nitrogen, 11 kg Phosphorus, 110 kg Potassium, 13 kg Calcium and 21 kg Magnesium per ha per year. However, some amounts of the cover crop biomass were lost due to decomposition during the year. These were left uncalculated.

4.3.4. Annual Crops

*Inter-cropping system with corn (**Zea mays**)*

Growth of corn inter-cropped with several tree species in the first block is shown in Plate 4.2, whereas the effects of the treatments on the corn yield are presented in Fig. 4.4.

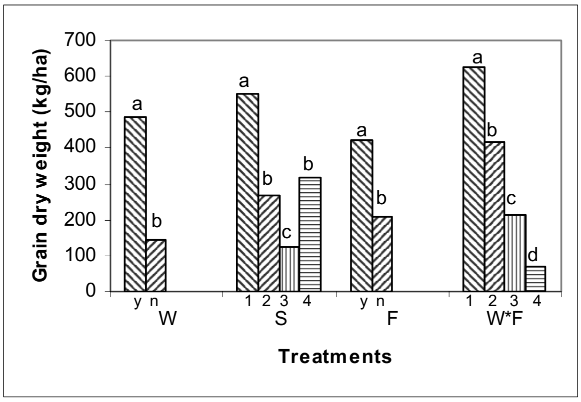
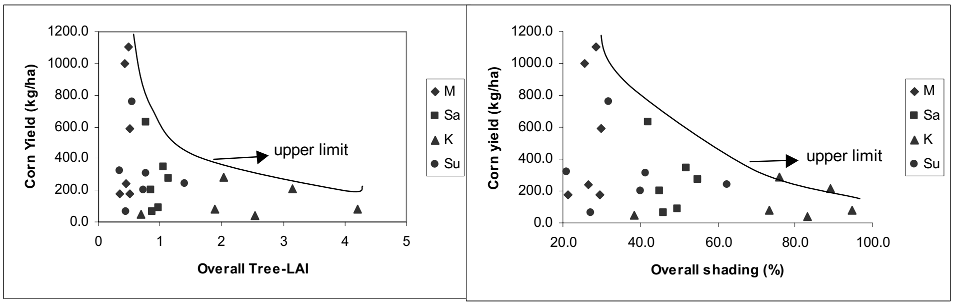


Fig. 4.4. Grain dry weight of corn (*Zea mays*) as an inter-crop in Block I. W=weeding treatment, [y (yes)= weeded, n (no)=not weeded]; S=tree species (1=mahogany, *Swietenia macrophylla*, 2= sungkai, *Peronema canescens*, 3=candle nut, *Aleurites moluccana* and 4=sukun, *Artocarpus altilis*); F=fertilisation [y (yes)=fertilised, n (no)=not fertilised]; W*F=interaction between weeding and fertilisation (1=weeded and fertilised; 2=weeded and not fertilised; 3=not weeded and fertilised; 4=not weeded and not fertilised). Bars followed by different letters (a,b,c or d) in the same treatment are significantly different ($P<0.05$) according to Duncan's Multiple Range Test (DMRT)

All treatments and interactions between those treatments (weeding and fertilisation) had a significant effect on the yield of the corn (Fig.4.4). Weeding activity increased the yield sharply. The corn yields under the four tree species differed significantly from each other. The highest corn yield was found under mahogany, followed by sukun and sungkai. The lowest one was found under candle nut trees. Fertilisation significantly stimulated the yield of the corn. Interaction between weeding and fertilisation also had a significant effect on the corn yield. The treatment W_1 (weeded and fertilised) increased the corn yield dramatically. It was followed by W_2 (weeded and not fertilised) and W_3 (not weeded and fertilised). The treatment W_4 remained behind.

In general, the corn yield under the tree stands in the first block was low. The mean value was 1,340 g 64 m^{-2} or 209.4 kg ha^{-1}. If we assumed that the ratio of land used by crop and by tree is 2:1, the corn yield per ha in mono-culture would be 314 kg. The highest average corn yield was 2666 g 64 m^{-2} under W_1 (weeded and fertilised) or 416.6 kg ha^{-1}, or 624.9 kg ha^{-1} when assuming that the corn was grown in mono-culture. This amount was still low when compared with corn grown in the open area. This might be because the trees shaded the crops, as shown by Fig.4.5.

As might be expected, there was a negative correlation between corn yield and overall tree-LAI as well as overall tree-shading. The higher overall tree-LAI and the overall shading by trees, the lower the corn yield. The corn yield was very low when the LAI was more than 1 and shading more than 40%. As the nutrients and water



A B

Fig. 4.5. Relationship between corn yield and overall tree-LAI (A), and overall tree-shading (B) in the first block. M=mahogany, *Swietenia macrophylla*, Sa=sungkai, *Peronema canescens*, K=candle nut, *Aleurites moluccana* and Su=sukun, *Artocarpus altilis.*

demand by the trees are likely related to the LAI as well, we can not distinguish between above- and below-ground competition as the main factor in the tree-soil-crop interaction.

As explained in par. 4.2.3, inter-cropping with corn was carried out two times in the third block. The second corn yield was higher than that in the first season. It ranged from 0.23 to 3.33 ton ha^{-1} with an average value of 1.98 ton ha^{-1}. This may be related to the application of fertiliser. In the first season, the fertiliser used was only organic or livestock manure and only a half of the plants were fertilised. In the second season, both organic and inorganic fertilisers were used. The relationships between corn yield, overall tree LAI and overall tree-shading in the first and second season in the third block are presented in Figs.4.6 and 4.7.

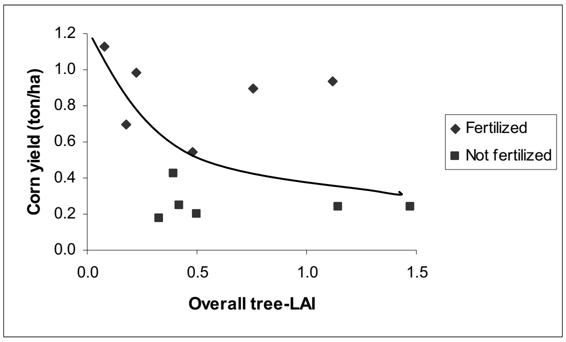
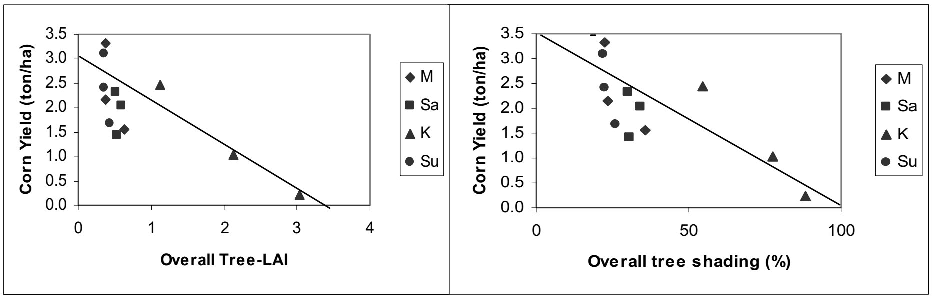


Fig. 4.6. Relationship between corn yield and overall tree-LAI in the first season in the third block



A B

Fig. 4.7. Relationship between corn yield and overall tree-LAI (A), and overall tree-shading (B) in the second season in the third block. M=mahogany, *Swietenia macrophylla*, Sa=sungkai, *Peronema* canescens, K=candle nut, Aleurites moluccana and Su=sukun, Artocarpus altilis

In both cropping periods the corn yields were reduced when the overall tree-LAI was more than one, yet an increase in nutrient supply appeared to increase crop yield, indicating that the tree-soil-crop interaction may be nutrient-based rather than a simple shading effect. In the second season, most of corn yields under candle nut with a dense and wide canopy were less than 1 ton per ha. Inter-cropping between corn and several tree species in the third block during the second season is shown on Plate 4.3.

*Intercropping with mung bean (**Vigna radiata**)*

Growth of the mung bean in the second block was heterogeneous among the sub-plots planted. No yield could be harvested from this crop, since a few days before harvesting, the crop was attacked by rats. The rats consumed most of the yield and only a small part was spared. Therefore, a normal yield of the mung bean, as an inter-crop under a stand of several tree species in the second block could not be studied.

Growth of the mung bean in the third block was not homogeneous over the sub-plots. One part survived and another part did not. The possible cause is a combination of shading and re-growth of *I. cylindrica.*

4.3.5. Dynamics of Soil Fertility

Soil properties, 24 months after establishment of the agroforestry plots, per blocks and per soil map unit, can be seen in the Table 4.4.

The average value of the pH was similar throughout the three blocks, and slightly lower than the initial average pH value of the soil at the initial condition (see Table 2.5). The organic carbon content ranged from 1.56 to 1.91 %. There appeared to be an increase in the content of $C_{org.}$ compared to the initial condition. The same

Table 4.4. Chemical soil properties of three agroforestry blocks, 24 months after establishment, per soil map unit. The first block is divided in unfertilised and fertilised corn (*Zea mays*), planted in the area.
uf=unfertilised, f=fertilised. Soil samples analysis by Biotrop Soil Laboratory, Bogor, 2001.

Blocks/soil map units	Chemical soil properties							
	PH (H_2O)	$C_{organic}$ (%)	N (%)	$P_{available}$ (mg kg^{-1})	K (cmol$_e$ kg^{-1})	Mg (cmol$_e$ kg^{-1})	CEC (cmol$_e$ kg^{-1})	Al (cmol$_e$ kg^{-1})
I: Usl 234 uf	4.6	1.56	0.13	1.18	0.12	1.56	11.25	2.14
MSl 233 uf	4.4	1.84	0.17	1.88	0.13	1.51	9.71	2.08
LSl 233 uf	4.4	1.72	0.16	2.26	0.14	1.26	9.61	1.87
LM223 uf	4.3	1.81	0.14	1.55	0.16	1.23	9.26	1.69
Average	**4.4**	**1.73**	**0.15**	**1.72**	**0.14**	**1.39**	**9.96**	**1.95**
I: Usl 234 f	4.1	1.70	0.18	2.65	0.15	1.04	8.36	3.26
MSl 233 f	4.4	1.63	0.17	2.20	0.16	1.52	10.36	2.30
LSl 233 f	4.8	1.68	0.17	2.25	0.14	1.37	10.38	2.11
LM223 f	4.4	1.61	0.17	1.91	0.14	1.26	9.55	1.94
Average	**4.4**	**1.66**	**0.17**	**2.25**	**0.15**	**1.30**	**9.66**	**2.40**
II: USl 233	4.4	1.57	0.14	2.36	0.13	1.03	9.74	2.44
MSl 443	4.1	1.62	0.15	1.73	0.13	0.84	10.33	3.12
LST 222	4.4	1.71	0.16	1.99	0.15	1.12	9.81	2.31
MM 233	4.3	1.60	0.17	2.10	0.14	0.91	10.17	2.59
Average	**4.4**	**1.63**	**0.16**	**2.05**	**0.14**	**0.98**	**10.01**	**2.62**
III: Ust 132	4.4	1.86	0.16	2.98	0.11	1.16	9.61	2.46
MSt 122	4.4	1.91	0.17	1.92	0.13	1.29	10.35	2.57
LSt 221	4.5	1.83	0.15	2.30	0.12	1.14	10.47	2.31
LSt 243	4.4	1.87	0.18	3.40	0.11	1.62	9.82	2.19
Average	**4.4**	**1.87**	**0.17**	**2.65**	**0.12**	**1.30**	**10.06**	**2.38**

positive change had occurred in the nitrogen content. The nitrogen content 24 months after the establishment of the agroforestry plots was more than two times that of the initial content, probably due to the leguminous cover crop. The available phosphorus and potassium content, however, decreased significantly if compared to the initial value. The fertilisation treatment in the first plot tends to increase the available P consistently (f versus uf plots), but at a very low absolute level. On the contrary, Mg content appeared to increase sharply. The cation exchange capacity (CEC) did not differ between the two measurements.

4.3.6. Farmers' Response and Local People's Opinion to the Agroforestry System Tested

Farmers' interest in the agroforestry systems tested was monitored in two ways, by the response to the experiment managed by the researcher and by the activities in the trial managed by the farmers.

The participation of the first group was assessed according to the terms of reference agreed between the researcher and each farmer. As explained in par. 2.5.1, the agreement arranged the rights and responsibility of the researcher and the land owners during the research period. All matters agreed upon were discussed with the respective farmers and their families as well as with the village heads before the agreements were written up and signed. The researcher had rights and responsibilities in managing the plots, and in preparing tree seedlings, seeds of annual crops, fertilisers and other materials including herbicides and pesticides. In addition, the researcher or the project had to provide and to pay daily workers to do the planting and maintain the trees, and to prepare and maintain the plots, including fire breaks and live fences or hedges. The participating farmers detain the property rights of the yield of all trees and annual crops. For trees, the farmers will own both the wood and the fruits. They also have the responsibility of cultivating annual crops in the plots in the second year or after harvest of the cover crop. The farmers had free choice of species of annual crops, of which the researcher then provided the seeds, and the same went for fertilisers. However, the farmers had to cultivate and maintain the annual crops, by their own labour without pay. These agreements were duly approved and signed by the researcher and by all three participating farmers.

In practice, however, none of the farmers could fulfil this agreement completely. In the first block, the respective farmer and his family only planted corn and weeded the soil in a part of the area. Afterwards, they left and started planting upland rice in the forest area. In the second block, the respective farmer only participated in making planting holes and spreading organic fertiliser. Daily workers performed the planting and weeding. In the third block, however, the respective farmer and his family participated actively. They planted the annual crop, corn, in two rotations in 2001 and they maintained it very well. Besides, they also planted green pea in certain sub plots. However, the farmer asked the researcher to prepare the land by full tillage before they planted that corn. Otherwise, he was not likely to cultivate the corn. Therefore, the researcher had to pay for costly full tillage land preparation. In the other two blocks, we did the minimum tillage in land preparation, since the topography of the sites was not flat and full tillage facilitates erosion.

The farmers' activities in the trials managed by farmer were monitored, including local methods of alang-alang management, tree planting, inter-cropping, maintenance of the plots, etc. Initially all five the participating farmers were active in managing their agroforestry plots. They planted tree seedlings at the right time, not long after the seedlings were transported from the nursery to each of the farms. They suppressed alang-alang in various ways and they cultivated annual food crops in the areas. Four of the five participants did inter-cropping with annual crops. The farmer who did not inter-crop maintained the trees by clearing and piling up the soil around the trunk in a radius of 50 cm. One farmer planted the trees in combination with pepper, a high-value crop in the area. Most of the farmers said that they did not like to combine pepper with other plants, since they expected that pepper could not produce the optimal yield when inter-cropped with other plants. None of the five farmers planted a cover crop.

The following paragraphs describe field visits, discussions and interviews with 45 local people to study their opinion and perception in terms of alang-alang grassland conversion into productive agroforestry.

In the first field visit, 6 months after the trees and cover crops were planted, more than 80 % of respondents stated that the research plots in their villages motivated them to use and to convert their alang-alang lands. Furthermore, 93 % of them expressed a desire to establish a similar agroforestry plots under arrangements such as they had seen. Circa 80 % of the respondents were optimistic that conversion of alang-alang grassland into productive agroforestry will achieve a sufficient result. However, they also mentioned were serious constraints to be solved, including devastation by wild pigs and fires. The villagers explained that several methods had been applied in preventing wild pig attacks, but the results were not satisfactory yet. The villagers were sure that the fire issue can be solved if a good co-operation among villagers can be built.

During the second field visit, 24 months after the agroforestry plots were established, more than 80 % of the respondents considered the agroforestry plots to be economically feasible and about 70 % of them expressed interest in joining a program if tree seedlings are provided. The positive role of the cover crop in improving soil fertility was recognised by most of the visitors, both during the first and the second visit. However, so far, there was no villager who adopted and planted cover crops in their farms, even among the five participating farmers involved in the development research. Some visitors of the main experiment worry about the dry leaves and litter of the cover crop, because they are highly inflammable during drought. Other villagers faced difficulties to obtain cover crop seeds.

4.4. DISCUSSION AND CONCLUSIONS

4.4.1. Suitability of Methods of the *Imperata cylindrica* Management

Spraying herbicide clearly leads to the greatest reduction of alang-alang biomass, and this method was significantly more effective than the pressing method. However, the tree growth was not significantly different between treatments and repeated herbicide application may be undesirable for micro-flora and -fauna in the soil, that are needed to build a new complex ecosystem. We could not perform an economic evaluation of the costs and benefits of the different *I. cylindrica* control measures, but it appears that the low-cost pressing method does lead to additional labour requirements for weeding in inter-crops, when compared to the tillage and herbicide methods.

4.4.2. Suitability of *Pueraria javanica* as a Cover Crop

The cover crop, *P. javanica*, was successful in the reduction of above-ground biomass of *I. cylindrica* in the first and the third blocks of the main research sites. Although, the alang-alang regrows after this cover crop was harvested, its biomass was no more than 30 % of the initial alang-alang biomass under all three methods of alang-alang reduction applied, even, in the period of 18 to 24 months after the agroforestry plots were established, when there was no inter-crop. In the second block, however, the cover crop only reduced alang-alang biomass by 50%, and 12 months after the cover crop was harvested, the alang-alang biomass was even higher than under initial conditions (when it was still recovering from a burn 3 months before and was only 0.75 m high). In several subplots no annual food crop was planted as the alang-alang biomass was considered too dense. The alang-alang in the second block produced abundant seeds after the fire, as was reported by Eussen (1980) and NRI et al. (1996), and this contributed to the poor control in this block

The cover crop, *P. javanica*, dominated land cover after 12 months, except in parts of the second block, especially were the pressing method had been used. Land cover by the dense canopy of the cover crop provided a favourable micro-climate to allow development of nitrogen-fixing micro-organisms. Besides, the undergrowth species play an important role in conserving the soil such as reducing surface flow of water, mainly in sloping areas (Murniati, 1995). The failure of the cover crop to suppress the alang-alang grass in the second plot was mainly due to very slow initial growth of the cover crop, probably caused by poor physical properties of the soil as well rather than low nutrient availability. The soil in the second block had the lowest field capacity and water holding capacity of the three agroforestry plots (see Table 2.6).

The amount of biomass produced by *P. javanica* grown in these study sites was similar to that of the same species reported from elsewhere. Hairiah and van Noordwijk (1987) reported that on an acid soil in Onne, Nigeria, *P. javanica* produced 2.2 Mg ha^{-1} dry matter, 14 weeks after planting. In our study, this species produced 7 Mg ha^{-1} dry matter, 12 months after planting. This biomass supplied an important amount of nutrients to the soil, i.e.133 kg nitrogen, 11 kg phosphorus, 110 kg potassium, 13 kg calcium and 21 kg magnesium. When compared with biomass produced by nitrogen-fixing trees, this biomass was considered to be high. Murniati et al. (2001) reported that biomass of *Gliricidia sepium*, *Leucaena leucocephala* and *Calliandra calothirsus*, grown as erosion buffer or terrace strengthening plants in allay cropping systems in South Kalimantan were 1.2; 1.8 and 3.7 Mg ha^{-1}year^{-1}, respectively. These nitrogen fixing trees were cut back 3 times a year at 50 cm above the ground, and required more labour than the cover crop *P. javanica*, once the latter is established . Of course, this boosted production because the reiterated shoots are fed by a well-developed root system, assisted by a developing soil micro-life.

4.4.3. Tree Effects on Crop Yield

Corn yields in the first plot, and at the first rotation in the third plot were low compared with other findings. Average grain dry weight of corn grown in agroforestry plots in South Kalimantan was 2.8 Mg ha^{-1} (Murniati, et al., 2001). However, at the second rotation in the third plot, the corn production increased to 3.33 Mg ha^{-1} (the highest level) or to 1.98 Mg ha^{-1} in average. This was probably caused by application of inorganic (N and P) fertiliser at the second rotation. In both sites, optimal growth and yield of corn was obtained at overall tree-LAI ≤ 1, and overall tree-shading $\leq 40\%$. The experiment did not allow for an analysis of the specific components of the tree-soil-crop interaction, and rather than direct shading effects, the relation between LAI and crop yield may have been due to unbalanced nutrient distribution linked to tree biomass development.

4.4.4. Changes in Soil Fertility after Two Years of the Agroforestry System Establishment

The use of the legume cover crop did lead to an increase of the organic carbon and especially the soil N content, but it is likely that P supply remained critically low on these soils of low inherent fertility.

4.4.5. Farmers' Participation and Perceptions

The practice of working together with the participating farmers in the three blocks of the main experiment indicated that those farmers only participate in the project as long as they receive a certain subsidy. Indeed, all means of production; such as seeds, fertilisers and if necessary pesticides were provided and the full yield was attributed to them. Still, quite a few left the agroforestry plots and went to the forest to do shifting agriculture and/or illegal cutting. Gaps did arise in the cropping patterns and the incomplete implementation of cropping activities confounded the experiment, making it more difficult to attribute differences in tree performance to specific treatments. This farmers' response, may have been stimulated by lack of trust in the results and success of the agroforestry plots, but it demonstrates that the opportunity cost of labour is high in these conditions and that farmer labour investment in conversion is likely to stay below the threshold needed for successful conversion. The situation in East Kalimantan, with opportunities for cash income from the surrounding forest contrasts with that in, for example North Lampung, studied by Purnomosidhi et al. (in press.). In this place, there was no opportunity left to obtain income from the forest and there was thus compelling reason to convert and to cultivate alang-alang grassland by local farmers. The absence of other opportunities in North Lampung can explain their stronger interest in agroforestry development. Overall, our experience shows that the expectation that agroforestry development on *I. cylindrica* grasslands would by itself contribute to a reduction of pressure on forest resources was not supported by the observations. Rather, it appears that depletion of forest resources is needed before the incentives for agroforestry conversion are competitive in the farmers' decision frame.

A contributing factor to the low participation of farmers in the experiments may have been the location of the plots in their *Lahan Usaha II* (see par. 2.2 and 2.5.1), 1.5 to 2 km away from the farmers' house and making it difficult to supervise the plots. The farmer in the third block, who lived only 500 m from the plot, closer by than the other two farmers managed his plot more intensively. On the contrary, when the farmers were free to choose their own location for the trees in the trials managed by farmers, most of them planted the trees close to their houses or in *Lahan Usaha I*. For this factor of distance also see Indrabudi (2002).

The different degrees of farmers' participation between the two groups can be explained by the interest of the researcher versus the farmer's opportunity. The first group of farmers, who participated in the main research, knew that researcher had a strong interest in all activities related to the plots and they realised their bargaining position. Therefore, although the farmers did not fulfil their responsibilities, they could expect the researcher to substitute those tasks to 'save her experiment'. The farmers in the second group had no similar opportunity, as the objective of the development research was to study how far farmer participation would go in development and adoption of the conversion of alang-alang grassland into an agroforesty ecosystem.

On-farm research reflects the real condition in the field. An improved agroforestry system must be tested at the level of the farmer himself, i.e. on-farm. It must be ecologically and agronomically sound, economically feasible and socially acceptable (Oldeman, 1985; Van Noordwijk et al., 1995). It is common that supposedly superior aspects of new technologies that emerged from research stations do not appear under on-farm conditions and under farmers' management (Williams, 2000). However, to achieve a valid and sufficient result, management of on- farm research should be shared exactly in the right way between researcher and farmer. It could be an experiment fully managed by a researcher or a development research fully managed by a farmer. A hybrid of the two, as emerged in our main research, an experiment managed by the researcher, with partial management by the farmer may not be satisfactory from a data collection perspective, nor as a test of how farmers will manage plots in a real situation. Proper trials managed by a researcher on farm can provide a biophysical standard for comparisons with on-farm research managed by a farmer.

A positive impression of local people paying a field visit to this project should be followed up with a concrete programme by the local government organisation (GO) or non-government organisations (NGO). Tree seedlings can be prepared by forestry services or local NGO's by means of establishing village nursery programmes. This programme should be followed by effective and sustained extension to facilitate information exchange.

Indeed, the main reason why the villager did not plant the cover crop was that the seeds are expensive. The species can be propagated vegetatively by means of stem cuttings. However, they can not be planted directly in the field. A simple nursery should therefore be set up and this will be labour intensive for field plots.

To close this chapter, several conclusions can be drawn.

- Herbicide spraying and ploughing are the most efficient methods to reduce alang-alang as a first step in the conversion of alang-alang ecosystems into agroforestry ecosystems. The pressing method may be the cheapest method to get acceptable tree growth, but was less attractive for inter-cropping and thus led to poorer overall control.
- As a cover crop, able to out-shade alang-alang after one year and so to prevent its recovery and to improve soil fertility at the same time, *Pueraria javanica* (Leguminosae – Fabaceae) is a good option.
- An overall tree-LAI ≤ 1 and an overall rate of tree-shading ≤ 40% are conditions for maximal corn yields by inter-cropping in a matrix of diverse trees species.
- For an active farmers' interest in the agroforestation techniques tested in the study sites some level of subsidy (provision of planting material) will be required, while agroforestration is unlikely to reduce the activities inside forest areas for direct income.

5. TREE ARCHITECTURE, ROOT DISTRIBUTION, AND ESTIMATION OF TREE BIOMASS

5.1. INTRODUCTION

5.1.1. Background

Man-made agroforestry systems that combine perennial tree species and annual food or cash crops may be ecologically sound, in that they use water, nutrients and light efficiently. They may be durable or sustainable and maintain a level of buffering to abiotic and biotic fluctuations by maintaining a degree of diversity in the potential products derived and therefore, of the crop species (Oldeman, 1983). It should, however, also be adapted to the socio-cultural condition of the local community and provide competitive returns to labor when compared with other locally available options.

In any agroforestry system interactions between trees and crops occur above and below ground, they are either direct or indirect. The interactions can lead to positive or negative effects for the trees or the crops as the components of an agroforestry system. Raintree (1983) classified the interaction between trees and crops under iso-resource conditions into three general relationships, namely supplementary, complementary and competition. The interaction is supplementary if the production of the one can be increased with neither an increase nor decrease of the other. The relationship is complementary when increasing the production of the one results in increases in the other, whereas competition occurs when increase in the production of the one results in decreases in the production of the other. The interactions are sometimes direct, for instance shading or allelopathy, and sometimes indirect, for example when both tree and annual plant are interacting parts of a microbiotic network such as a community of soil fungi and bacteria (cf. Oldeman, 2002).

The above-ground parts of trees and crops primarily interact in light capture (with secondary effects via microclimate and biotic consequences thereof), while below-ground they mainly interact in the distribution of water and nutrients uptake (Van Noordwijk and Purnomosidhi, 1995). Distribution of water and nutrients among tree and crop roots is co-determined by above-ground demand for those matters and the possibilities for uptake (Van Noordwijk and Purnomosidhi, 1995). Further, the desirable root architecture of trees differs between sequential and simultaneous agroforestry systems. In sequential systems, extensive tree root development may enhance nutrient capture and transfer substances to subsequent crops via organic, often microbial pools. In simultaneous systems, tree root development in the crop root zone leads to exclusion of other roots from parts of the rhizosphere volume. However, if the tree roots occupy the volume just underneath the annual crop roots, they can capture nutrients lost from the crop root zone and can therefore act as ‘safety-nets’ against leaching (Suprayogo et al., 2002).

Transmission of light, carbon dioxide and rain among above-ground parts of trees and annuals are influenced by the morphological expression of major components of tree architecture that determine the strategic form of the crown and the distribution of the foliage (Oldeman, 1992; Vester, 1997). The architecture of a tree as was defined by Hallé et al. (1978, p. 74 and 75) as "the visible, morphological expression of the genetic blueprint of a tree at any one time". The concept, therefore, is not static. It takes dynamic processes into account. Furthermore, Hallé et al. (1978, p. 75) defined the architectural model as "the growth program of a tree which determines the successive architectural phases of a tree". The architectural model of trees may be similar and may be different among the species, since the similarities and the differences are not necessarily dependent on taxonomy (Hallé et al., 1978). However, the model is hereditary and has a certain flexibility allowing adjustment to the local environment (Vester, 1997).

The growth pattern is defined by the activity of meristems. The activity of apical meristems, resulting in primary growth, has a double function. These meristems both build the axes and steer the development of lateral organs and meristems. Their activity results in axes bearing leaves and their axillary meristems giving rise to new axes or flowers (Oldeman, 1990; Crabbé, 1987 *in* Vester, 1997). The arrangement of organs along the axis and its dynamics characterise the nature and degree of differentiation in an axis. Orthotropic and plagiotropic axes are distinguished according to their direction of growth and the arrangement of their lateral organs. The orthotropic axes are vertical and most often form leaves in a spiral, whereas plagiotropic axes are horizontal with leaves arranged in a dorsiventral pattern. An axis is called determinate if its end meristem is programmed to lose its meristimatic characteristics, for instance, by forming an inflorescence. The axis is indeterminate when there is no programmed limit to the meristematic functioning of its apical meristem. Rhythmic and continuous branching are distinguished on the basis of the branching periodicity. Branching is rhythmic when branching periods alternate with periods without branching, otherwise branching is continuous (Hallé et al., 1978; Oldeman, 1990 and Vester, 1997). If in an otherwise continuous branching pattern, branches are omitted unpredictably in some axils but are formed unpredictably in others, Hallé and Oldeman (1970) called this phenomenon diffuse branching.

Hallé et al., (1978) described 24 models of tree architecture, 21 of which are shown in Fig. 5.1 (after Oldeman, 1990). Hallé and Oldeman (1970) had named those models after botanists who worked on the morphology of the plants. For example, a tree that develops only one axis and dies after flowering once at its end, e.g. *Agave* spp., was dubbed *Holttum's model* because this botanist was the first to describe an example of this method of growth. A tree that develops an orthotropic, continuously growing axis with plagiotropic axes developing from every leaf axil, e.g. *Coffea arabica* L., corresponds to Roux's model. The branching pattern of trees is the basic pattern of the construction of their crown shape. Orthotropy or plagiotropy, definite or indefinite growth of axes in a tree determine width and length of the tree crown. The orthotropic branches with indefinite growth tend to carry the tree crown as high as possible towards the vegetation canopy, so it contributes to the crown length

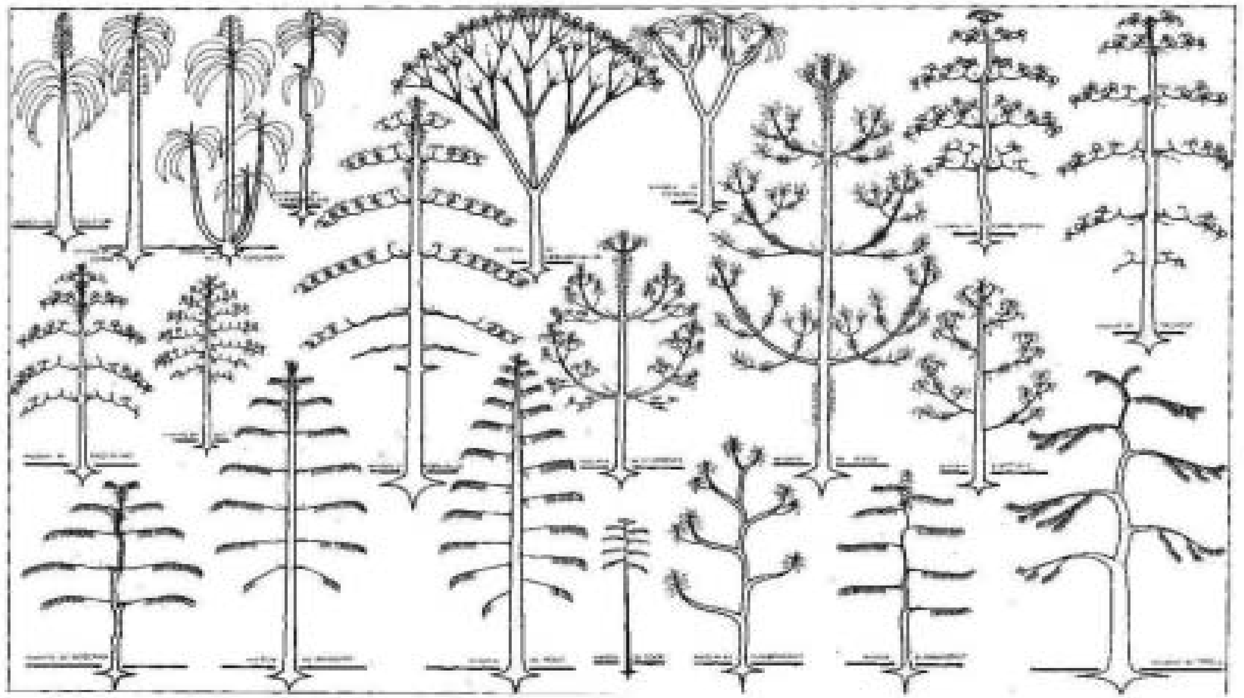


Fig.5.1. Architectural models of trees according to Hallé and Oldeman (1970), after Oldeman (1990)

or crown depth and hence determines the strategy of crown positioning. The plagiotropic branches with definite growth usually tend to spread out the tree crown as wide as possible towards places where there is light or water, so they determine the strategy of resource interception (Kahn 1978, according to Oldeman, pers. comm.).

The overall crown shape is three-dimensional. Crowns have a highly variable physiognomy; in between relatively dense conoids to wide open hemispherical shapes (Brack, 1999). This physiognomy is not its architecture. Crown architecture is the build-up by well defined axes, according to well defined principles of branching, of a well defined crown, the outer shape of which is its physiognomy. Many rather simple surfaces have been used to simulate the physiognomy of the crowns in forest simulation models. For two-dimensional images, Brunig (1977) and Werger et al. (1984) used rectangular crown shapes on perpendicular stems. Koop (1989) modelled a tree crown by drawing a three-dimensional crown projection to the ground. In this model, the tree crown was calculated and depicted as an ellipsoid shape for broad-leaved trees and as a cone-like shape for coniferous trees.

In the current study the physiognomy crown shape was classified according to the criteria made by the Direktorat Jenderal Kehutanan (1976). The crown is “conoid or pyramidal” when the wider part is found at the base of the crown and becomes smaller to the top of the crown. The crown shape is “paraboloid” when crown length/depth is more than two times the crown width and the width is equal along the trunk. The crown shape is “hemispherical” when the wider part of the crown is located in the middle of the crown length and the crown length nearly equals the crown width.

Based on the direction of the roots, Oldeman (1990) classified roots as either positropic (growing downward in the direction of gravity), diatropic (horizontal and growing perpendicularly to the direction of gravity), negatropic (growing vertically upwards, against gravity) or mixed (roots that start growing one way and change their orientation later). Besides, Oldeman (1990) coined terms on the basis of root longevity as macrorrhizae, brachyrrhizae and root-hairs. Macrorrhizae are massive, long-living roots that function as food and water-transportation channels and provide mechanical support; brachyrrhizae are slender, shorter-living roots that function as absorbing and metabolic organs, while root-hairs are the shortest living root organs and function as absorbing tissue. There is a loose analogy with branches, twigs and leaves in the above-ground part of plant.

The distribution of a root system in space and time is influenced by both the genetic nature of the plant and by the local soil condition (Huck, 1983; Atger, 1992). Root system performance has to be explicitly characterised in selecting tree and crop species for mixed cropping or agroforestry systems. Otherwise, the basis of plant selection for particular agroforestry designs, and the arrangement and management of them will necessarily be incomplete and brings risks of unwanted effects. In natural secondary forest, the organisms either search, accept and use resources, or die inside the higher organisation level of the ecosystem (Vester, 1997; Rossignol et al., 1998). It is in imperfectly designed artificial, human cropping systems that plants and other organisms die because they are placed in each others’ way and so become enemies or competitors. Many failures in land use designs are due to negligence of the subterranean part of the ecosystem, including its micro-flora and micro-fauna (Oldeman, 2002).

Tree root distribution can be approached according to the direction of proximal roots, the shoot/root ratio and an index of ‘root shallowness’ (Van Noordwijk and Purnomosidhi, 1995). The direction of proximal roots, i.e. roots originating from the stem base or as laterals from the top part of the taproot, may be vertical or horizontal depending on the angle between root and ground surface. Shoot-root ratio is a value, which compares the parts of a tree above and below the ground. The higher the shoot-root ratio, the larger the above-ground part of a tree, which, in its turn, contributes to the suppression of *Imperata cylindrica* in the context of agroforestry establishment on the grassland for shade-based alang-alang control. The precise value of the shoot-root ratio may be calculated on the base of either dry weight or total biomass of the shoot and root parts. However, in the present project, a non-destructive and simple observation method was developed, based on the cross sectional area of all proximal roots and the tree stem at breast height. It thus compares total transport capacity of shoot and root, if we assume that the size of individual xylem vessels is constant (and bound by the risk of cavitation) and the proportion of functional transport tissue in the cross sections is constant as well. An index of root shallowness was defined as the comparison between the horizontal root fraction and the shoot-root ratio (Van Noordwijk and Purnomosidhi, 1995).

In the previous paragraph, we discussed branching models, mainly depending upon the arrangement of organs along the axis. Here, the branching pattern will be discussed in relation to the scale or size of the branches, both in stems and roots, in order to estimate the biomass of a tree, or a tree population if average values are used. A tree stem functions as a traffic facility for sap movement in the tree. An ascending stream from the roots to the leaves brings water and nutrients up through the xylem, and a descending stream from the leaf to the roots brings photosynthetic products down through the phloem (Zimmermann, 1963; Oldeman, 1990). When a constant volume of sap passes through the tissues, the cross sectional area of a tree’s main stem has to be approximately equal to the sum of the cross sectional areas of its branches (Leonardo da Vinci, 1506, *ex* Zimmermann and Brown, 1971; Mandelbrot, 1983). A similar rule might apply to the roots. However, the cross-section of a stem or root also includes dead tissues left behind in earlier parts of a tree’s life. These add to the diameter, but not to the sap stream, so that the Rule of da Vinci only is approximate. Older axes are thicker than they should be by the rule.

Another parameter that can express the root distribution is “the gini coefficient (g)”. The “gini-coefficient”, originates from socio-economic research and was first used to describe the relative equity in income distributions (Anonymous, 1993; Khan, 1997). However, it can also describe the root distribution according to the number and size of the roots. Physiologically, the analogy is clear, because the distribution of the sap-stream over the roots is the equivalent of a “biological income distribution”. The gini-formula is $F=X^g$, F and X being values on a relative scale in between their minimum and maximum values. F is the cumulative frequency and X is, in this case, the cross sectional area of all proximal roots of a single tree. When $g=1$, the roots are distributed uniformly over all sizes; when $g<1$, there are relatively more thin roots (microrrhizae) than thick roots (macrorrhizae) and if g > 1, the inverse is true. The functional definition of macrorrizae and microrrhizae given above explains the significance of these distributions.

Biomass is defined as the total amount of above-ground living organic matter in trees expressed as oven-dry weight, in tons per unit area, i.e. per tree, per hectare, per region, or per country (Brown, 1997). Oldeman (1990) stated that the average values for biomass per hectare do not have the same meaning for different forest ecosystems. Moreover, Müller and Jörgen-Nielsen (1965, *ex* Oldeman, 1990) reported that the biomass in a tropical rainforest (the ancient Anguédédou forest in Côte d'Ivoire, now extinct) is slightly less than the biomass in a temperate forest in Denmark. This is caused by much higher turnover rates in the tropics. Two different methods have been used widely in determining the biomass of trees and/or forest, i.e. direct harvesting method, destructive, and the indirect estimation method, non-destructive estimation method based on allometry (Chapman, 1976; Satoo and Madgwick, 1982).

Brown (1997) reviewed several regression equations for estimating biomass of tropical trees depending on the climatic zones (dry, moist and wet). The equations are based on the diameter of stem at breast height or the basal area and should be applied for estimating biomass of trees in a stand. For trees grown in lines or in more open conditions, she suggests to develop new regression equations, since trees in this condition generally display different branching patterns and are likely to have more biomass for a given diameter than a tree with a similar diameter grown in a stand. Although Brown does not cite other authors, her facts fit in perfectly with Oldeman's h/d relations (1974, 1990), which take into account the change in physiognomy between a model-conform crown in a stand versus a crown composed by many model-conform sub-crowns in more stressed environments or in old trees.

It is well known since centuries, that trees grown in a closed forest have a crown shape very different from isolated trees. When trees grow in an open area, foliage is produced almost to ground level by prolific reiteration in the form of stem suckers (see Hatta, 1999). As such trees mature, their foliage increases exponentially. However, when the trees grow in a closed forest, the crowns are shaded by neighbouring trees and the amount of foliage for a tree of a given diameter is vastly smaller than in trees of the same species grown in the open.

Van Noordwijk and Mulia (2002) stated that methodological short-cuts to the empirical approach for establishing such equations are desirable for estimating tree biomass in mixed forestry or multi-species agroforestry systems. For this purpose, Van Noordwijk and Mulia (2002) developed a software, i.e. Functional Branching Analysis (FBA), based on an allometric equation $Y = a\ D^b$, where Y is tree biomass, and D is stem diameter at breast height while a and b are intercept and slope (power) of regression, respectively. The software can not only predict amounts of biomass, but other tree properties as well, such as total leaf and root areas, or total shoot and root length. The method was developed on the basis of non-destructive and easy observation. The software was built according to the fractal or self-repeating models. The models are essentially based on assumptions of 'self-similarity' across scales, meaning that a picture of a branching point looks the same, whether this picture is made from the first or last branching point of a tree. The size of the picture is always relative to the diameter of the branches considered. Mandelbrot (1983) said that aboveground trees, root systems, rivers and road networks share common properties, which have been recognised on the basis of 'fractal' analysis. Fractal properties can emerge if a relatively simple set of rules is applied consistently across a range of scales, e.g. Leonardo da Vinci's rule, saying that the diameters after a branching point are a certain proportion of the diameter before branching. If such rules are applied repeatedly, a form can be constructed with remarkable similarity to a tree or a river system. This form is sufficiently congruent with natural tree forms, such as those shown by Hallé and Oldeman (1970), Hallé et al. (1978) or Oldeman (1990, 1992, 2002) and for roots by Atger (1992), to be used as a predictive tool for the distribution of size and mass.

5.1.2. Research Objective and Research Questions

The overall objective in this chapter is to study tree root distribution and biomass production in several tree species, with reference to the young experimental agroforestry system, just established on *I. cylindrica* grassland. Therefore, the scientific questions are:

1. Which tree species have a crown shape and root distribution that can integrate itself optimally in the designed agroforestry system?
2. Are there differences between timber and multipurpose trees in their biomass, particularly in early development?
3. Is the estimated biomass of trees by the FBA software similar to the biomass obtained from the complete harvesting method?

5.2. MATERIAL AND METHODS

5.2.1. Tree Architecture

The architectural model of a tree, especially its part above the ground, was observed on the basis of the trunk characteristics, branching pattern, branch differentiation and reiteration. Reiteration is the formation of a model-conform structure from a vegetative meristem, not from a seed. Four tree species planted on degraded alang-alang grassland, as discussed in chapter 3 and 4, were observed for their architectural models. This tree plantation was still young, 2 years old, it consisted of three blocks (see Fig.2.2) and it accommodated four tree species, namely mahogany (*Swietenia macrophylla*), sungkai (*Peronema canescens*), candle nut (*Aleurites moluccana*) and sukun (*Artocarpus altilis*). In comparison, mature trees of each tree species growing outside the study blocks were also observed. The description of each tree species, then was cross-checked with the available literature, and attributed to an architectural model described by Halle and Oldeman (1970).

5.2.2. Root Distribution

Tree roots have different orientations (see par. 5.1.1). For practical purposes, diatropic root is classified in the model as a horizontal root (H_{root}) if the angle between the root and the vertical is more than or equal to 45°. When the angle is narrower than 45°, the root is classified as a vertical root (V_{root}), either positropic or negatropic. Some tree species form vertical roots in the early period of their life, other trees form them later (Atger, 1992). The horizontal root fraction is the share of horizontal roots in the total amount of roots.

The proportion of total roots (horizontal + vertical) compared to the above-ground parts of a tree, usually known as shoot-root ratio, in a certain period usually differs among the tree species. The proportion can be described by means of graphs representing the relationship between the cross sectional area of stem (square of the stem diameter) and the sum of crosses sectional area of the roots (sum of square of the diameter of all proximal roots). Another comparison is the relationship between the cross sectional area of the stem (parameter: the squares of the stem diameter) and the sum of the crosses sectional area of the roots (parameter: sum of squares of the horizontal root diameters). The relationship between the cross sectional area of the stem (parameter: square of the stem diameter), and the sum of the crosses sectional area of vertical roots (parameter: sum of the squares of vertical root diameters) may indicate the transport opportunities for the tree during long dry periods when it has to rely on deeper layers of the soil profile.

Object and sampling technique

The object of these studies was the young agroforestry tree plantation in an experimental system, just established on degraded alang-alang grasslands as discussed in chapter 3 and 4. There were three blocks of tree plantations (see Fig. 2.2) where each block comprises four tree species, namely mahogany (*Swietenia macrophylla*), sungkai (*Peronema canescens*), candle nut (*Aleurites moluccana*) and sukun (*Artocarpus altilis*). Soils are moderately well drained with an effective soil depth from 85 to 135 cm. Soil texture varies from clay loam, sandy clay and sandy clay loam, with a pH (H_2O) of 4.5 to 5.5. The CEC of the soils is low to moderate (8 to 17 $\text{cmol}_e\ \text{kg}^{-1}$). The average monthly precipitation during the first two years of the tree plantations is 258 mm (for details see par.2.5).

Six trees were taken as sample trees of each tree species in each block, two in each of the three toposequential positions (top, slope and valley). The sampling was based on choice by eye, based on field experience, of healthy, average trees. In total, 18 individual trees of each species were observed, measured and recorded in the three blocks together.

Data collection and analysis

The tree root data collection was carried out two times, namely at 12 and 24 months after planting time. Tree roots were dug up and exposed as shown on Fig. 5.2. The diameter of all proximal roots (d_r) was measured at a distance of 20 cm from the tree base. So was the angle of the roots to the ground surface. This is the angle complementary to the one with the vertical, used as a standard in our definitions because it is more constant than the soil surface. The stem diameter was measured at 25 cm above the root base when the trees were 12 months old; at 25 and 130 cm above the roots when the trees were 24 months old.

The horizontal root fraction was calculated with the root numbers and diameters. It is the ratio between sum of squares of the horizontal root diameters and the sum of the squares of all root diameters. The formula is as follows:

$$\text{Horizontal root fractions} = \frac{\sum_{1}^{n_h} d_r^2, H_{root}}{\sum_{1}^{n} d_r^2, H{+}V_{root}}\,,$$

where n_h = number of horizontal roots
n = number of all (horizontal and vertical) roots

The shoot-root ratio is calculated from the square of the stem diameter (d^2) and the sum of the squares of all root diameters ($\sum d_r^2$, $H{+}V_{roots}$) of individual trees. The formula is the following one:

$$\text{Shoot-root ratio} = \frac{d^2}{\sum_{1}^{n} d_r^2,}\,,$$

where n = number of all roots (horizontal and vertical)

The gini coefficient, as mentioned earlier, describes the root distribution according to number and size of the roots. It was calculated based on a cumulative frequency (F) and relative size or cross sectional area of all roots (X), with the following formula:

Cumulative frequency = $[(d_r - d_{r\,min})/d_{r\,max}]^2$, where d_r = diameter of roots

Fig. 5.2. Exposing and measuring roots of a candle nut tree, 24 months after planting

5.2.3. Tree Biomass Estimation

In order to estimate the tree biomass, the trees were observed and measured in the first block of the agroforestry system established on *Imperata cylindrica* grassland. The observations were carried out on four tree species, namely mahogany (*Swietenia macrophylla*), sungkai (*Peronema canescens*), candle nut (*Aleurites moluccana*) and sukun (*Artocarpus altilis*). Several individual trees of each species were selected as sample trees, on the basis of an intentional choice of healthy and average trees as judged by eye according to the field experience of the researcher.

Parameters of nested branching characteristics above- and below-ground level have been used by many authors, most recently by Van Noordwijk and Mulia (2002). They include the number of branches (n), the transfer coefficient of cross sectional area (p), an allocation coefficient among branches (q), and a regression coefficient between diameter and length of links. The term “link” refers to a section of stem or branch between two branching points. The value p is an empirical proportionality factor (coefficient) between the total cross sectional areas, before and after branching. Another parameter, q, or the allocation coefficient among branches, is defined as the ratio of the largest link diameter to the sum of all the branch diameters (see Fig.5.3).

Data collection

Diameter and length of links and number of leaves along each link were measured. The diameter was measured twice, cross-wise, at the middle of the link. The stem or link number and the parent number of that stem were recorded. The main stem was given link number 1, its offspring are number 2 and 3, the offspring of link number 3 are number 4 and 5, and so on (see Fig.5.3). Therefore, the number of the parent of the main stem is zero. For reliable estimates of the fractal branching parameters, a minimum number of 50 branching points have been observed in each tree species (Van Noordwijk and Mulia, 2002). The length of bare tip on final links was measured too, if and when present.

Dry weight per volume of wood (wood density) was estimated by taking a range of wood samples. FBA classifies the woody part of the tree into three categories: wood, branch and twig. The classification follows the diameter of the log; if the diameter is less than 2 cm, it is a twig; if it is in between 2 and 10 cm it is a branch, and all else is wood. In the present object of study, however, the sample trees are still young and small, so the classification was modified for branch and wood. The log was called a branch when the diameter was more than 2 cm and less than or equal to 7 cm (2 cm $< Ø \leq 7$ cm) and it was called wood when its diameter more than 7 cm ($Ø > 7$ cm). The wood, branch and twig dry weights were determined by drying those samples in an oven at 70°C until a constant weight has been attained.

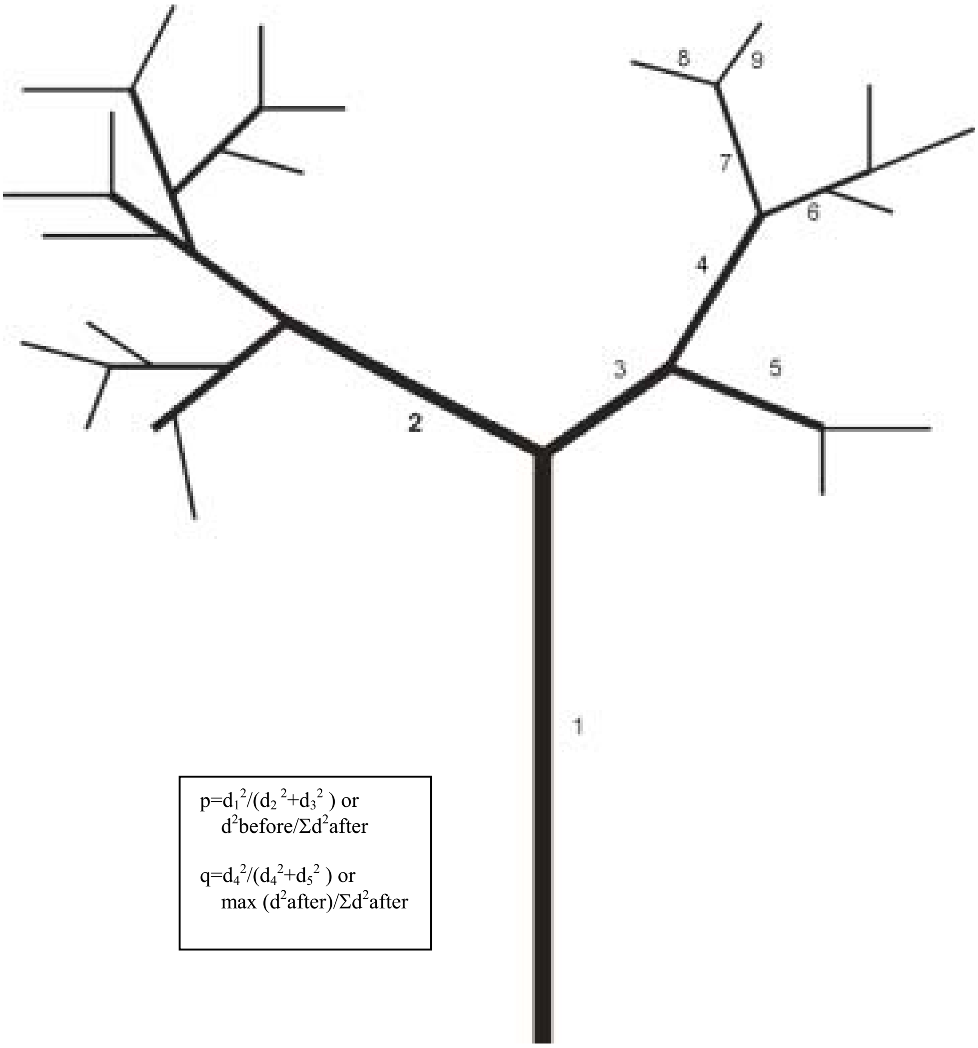
Several leaf samples of each species were collected to determine the average area of a single leaf and the specific leaf area (SLA). The SLA is defined as the surface area of leaves (one side) per unit dry weight (cm^2/g). The leaf area was calculated by means of a leaf punch method. The dry weight of the leaves was determined by drying the samples in an oven at 70°C during 24 hours.

Beside the indirect estimate method by means of FBA software, the direct harvesting method in calculating the tree biomass was applied in order to compare the results. The length and diameter were measured in all sections of logs as well as the leaf number. Wood, branch and twig density; SLA and average single leaf area as determined as an input into FBA software are also used in the harvesting method.

Data analysis

Branching parameters as input data of FBA were calculated by using a program named FbaHelpFile as they were difficult to calculate manually. Those parameters covering n_sub, mean_p, mean_q, range_p, range_q, intercept, slope, range_L, dmin, dmaxfin, dzerofin and maxfindens.

N_sub is the average number of branches. Mean_p and mean_q respectively are the averages of p and q where p is the ratio between sum of diameter squares before and after branching; q is the ratio between the largest diameter square after branching and the sum of the diameter square after branching. Range_p and range_q are the range between the maximum and the minimum of p and q to their mean. Intercept and slope refer to intercept and slope of regression equation between diameter and length of links, whereas range_L is the relative range for links length. Dmin is the diameter of a link when the branching was stopped, while dmaxfin and dzerofin are the diameter of a link when the leaves or fine roots density reached maximum and zero, respectively. The last, maxfindens is the number of leaves per centimetre of links.



$p=d_1^2/(d_2^2+d_3^2)$ or
d^2before/Σd^2after

$q=d_4^2/(d_4^2+d_5^2)$ or
max (d^2after)/Σd^2after

Fig.5.3. Link numbers in a tree, and the formula of the transfer coefficient (p) and allocation coefficient (q) among the branches

The branching parameters and the other data, such as Specific leaf area (SLA), wood density, etc. were used as input data of the FBA software. Biomass of above- ground parts of the tree species was displayed as output of the program.

5.3. RESULTS

5.3.1. Tree Architecture

The architectural models of the four tree species planted in the agroforestry system are the following ones:

Mahogany (*Swietenia macrophylla* King, Meliaceae), Plate 5.1A

Mahogany trees are evergreen or deciduous, small to medium-sized trees up to 1.5 m diameter and 30 m tall. The tree has a monopodial trunk, which grows rhythmically and indefinitely, bearing sympodial branch complexes. Morphogenetically, the axes forming the branches themselves are equivalent to the trunk. These axes are orthotropic with definite growth. Each branch has spirally arranged leaves; usually a leaf carries 4 pairs of opposite leaflets. Flowers are always laterals.

According to Hallé et al. (1978), the architecture of mahogany trees conforms to Rauh's model. The architecture of this model is defined by a monopodial trunk, which grows rhythmically and so develops tiers of branches. The branches themselves are morphogenetically equivalent to the trunk. Flowers are always lateral and without effect on the extension growth of the shoot system.

In the early life span (first two years) of mahogany trees, the widths of their crowns are constant along the trunk, whereas the crown length is about twice the crown width. So, the physiognomy crown shape of the mahogany trees is classified as a paraboloid.

Sungkai (*Peronema canescens* Jack., Verbenaceae), Plate 5.1B

Sungkai trees are evergreen or deciduous, small to medium-sized trees up to 30 m tall. The main trunk is monopodial with indefinite, rhythmic growth, bearing sympodial branch complexes. Branch axes are orthotropic with definite growth. In its early development, the branch shows a repetition of the monopodial growth of trunk, then sympodial branches begin to appear, due to terminal flowering. Each branch module has spirally arranged leaves (opposite-decussate); leaflets are in opposite or sub-opposite in 3 to 11 pairs and are up to 35 cm x 7.5 cm. The inflorescence is paniculate, terminal or in the axils of the uppermost leaves, large and widely erect, 25 to 60 cm high (Hatta, 1999).

Further, Hatta (1999) claimed that the architecture of sungkai represents the Scarrone's model, converging when older with Leeuwenberg's model. In young sungkai trees the architecture indeed conforms to Scarrone's model, and in adult and usually much reiterated trees, fragmentation and reduction make it resemble Leeuwenberg's model.

The physiognomy crown shape of sungkai trees during the young stage is quite similar to the crown shape of mahogany trees, although their architecture is distinct.

The width of their crown is constant along the trunk, whereas the crown length is about twice the crown width. Their crown formed a paraboloid shape.

Candle nut (*Aleurites moluccana* Willd., Euphorbiaceae), Plate 5.1C,E

Candle nut trees are evergreen, small to medium trees. The main trunk is monopodial with rhythmic and indefinite growth, bearing sympodial branches. The axes are orthotropic and show definite growth due to terminal flowering. Each axis has spirally arranged leaves. The leaves are cut into 3 to 5 pointed lobes.

Hallé et al. (1978 p.213), described Scarrone's model as follows: "the architecture is determined by an orthotropic rhythmically active terminal meristem which produces an indeterminate trunk bearing tiers of branches, each branch-complex orthotropic and sympodially branched as a result of terminal flowering". Based on the above morphological expression of the candle nut trees, they conform to Scarrone's model (Plate 5.1C). We could find no evidence for the tree to show either Petit's model (Hallé, 2002, pers. comm.) or Champagnat's model (Edelin, 2001, pers. comm.).

Candle nut trees show hemispherical crowns in their first two years of their life, the wider part of the crown being located in the middle of the crown length and the crown length being nearly equal to the crown width.

Sukun or breadfruits (*Artocarpus altilis* Fosberg, Moraceae), Plate 5.1D,F

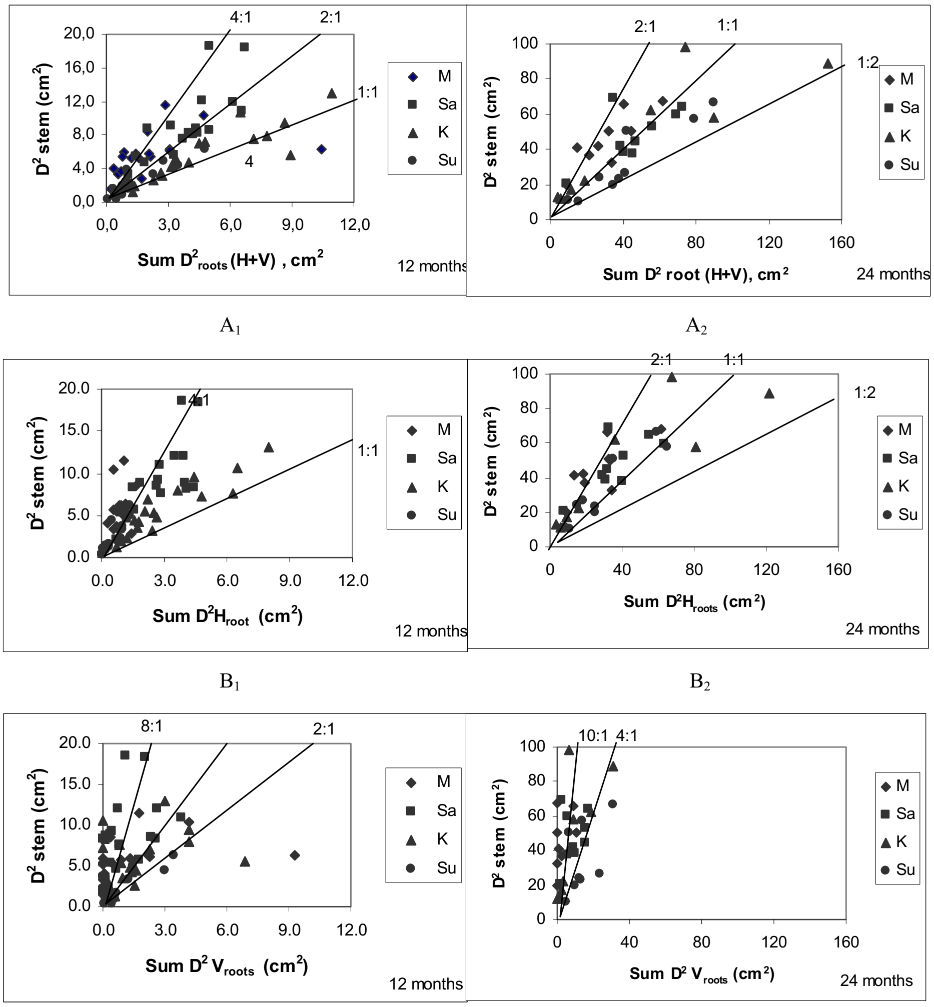
Sukun is a monoecious tree, up to 30 m tall, evergreen in the humid tropics, semi-deciduous in monsoon climates. The free trunk is straight, 5 to 8 m tall, 0.6 to 1.8 m in diameter. The trunk of clonally propagated trees is branched low; twigs are spreading with pronounced leaf and stipule scars and lenticels. Leaves are alternate, ovate to elliptical, undivided when young, older ones entirely or deeply pinnately cut into 5 to 11 pointed lobes, thick, leathery, dark green and shiny above, pale green and rough below. Fruits are syncarps formed from the entire inflorescence (Rajendran, 1941).

The main trunk of sukun trees is monopodial with indefinite and rhythmic growth, bearing sympodial branch complexes. The branch axes are orthotropic with indefinite growth (Plate 5.1D). Hence, the architectural model of sukun trees is Rauh's model (Hallé et al., 1978).

Similar to the candle nut, sukun also shows a hemispherical crown in the first two years of its life.

5.3.2. Root Distribution and Shoot-root Ratio

Distribution of roots (horizontal and vertical roots) and their proportions to the stem expressed on the basis of the cross sectional area of each root fraction and the stem of the four tree species at 12 and 24 months after planting are presented in Fig. 5.4.



A₁ A₂

B₁ B₂

C₁ C₂

Fig. 5.4. Distribution of roots and their ratio to the stem according to cross sectional area of the four tree species, 12 and 24 months after planting. M=Mahogany, *Swietenia macrophylla*, Sa=Sungkai, *Peronema canescens*, K=Candle nut, *Aleurites moluccana*, and Su=Sukun, *Artocarpus altilis*. A. total root (H+V); B. horizontal roots (H); and C.vertical roots (V)

Figure 5.4 (A and B) shows that mahogany and sungkai have higher stem-root ratios than candle nut and sukun. The graphs A and B also indicate that the horizontal root fraction is the dominant part of the roots, mainly at 24 months after planting. On the contrary, the vertical root fraction, as presented by graphs C (C_1 and C_2), comprises a small part of all roots only and sometimes there were no vertical roots at all, so this value is zero. The proportions of the vertical roots to the stem were ranging from 10:1 to 2:1. However, sukun shows the exception. It has strong vertical roots when observed 24 months after planting. Twelve months after planting (A_1 and B_1), nearly all points were in the range between 4:1 and 1:1, while for data of 24 months after planting (A_2 and B_2), most of the points sit in the range between 2:1 and 1:2. This means, that in the period of 12 to 24 months after planting the roots show higher diameter growth rates than the stem.

The horizontal root fraction and shoot-root ratio of the four tree species according to their topo-sequential position can be seen in Table 5.1.

Table 5.1. Horizontal root fraction and shoot-root ratio of four tree species according to the topo-sequential position of the trees, 12 and 24 months after planting. Values followed by different letters are significantly different ($P<0.05$) according to Duncan Multiple Range Test (DMRT), NS=no significant difference ($P>0.05$))

Treatments	Horizontal root fraction		Shoot-root ratio		
	12 months	24 months	12 months, d-25	24 months, d-25	24 months, d-130
Tree species					
Mahogany (M)	0.64^{a}	0.90^{a}	4.37^{a}	1.64^{a}	0.72^{NS}
Sungkai (Sa)	0.73^{a}	0.81^{ab}	2.50^{b}	1.20^{ab}	0.73
Candle nut (K)	0.66^{a}	0.83^{ab}	1.28^{b}	1.32^{ab}	0.58
Sukun (Su)	0.46^{b}	0.69^{b}	2.09^{b}	0.79^{b}	0.54
Tree position					
Top (T)	0.65^{NS}	0.80^{NS}	2.64^{NS}	1.17^{NS}	0.58^{NS}
Slope (S)	0.63	0.80	2.97	1.21	0.65
Valley (V)	0.59	0.82	2.06	1.34	0.70

The horizontal root fraction of sukun is significantly lower than that of the three other species at 12 months after planting and also significantly lower than mahogany, but similar to sungkai and candle nut, 24 months after planting. Sukun has the lowest horizontal root fraction and the highest vertical root fraction among the four tree species. In other words, vertical root growth in sukun is stronger and faster. The position of the tree on topo-sequence had no significant effect on the horizontal root fraction. For data observed after 12 months, there is a tendency toward a higher position of the trees on the topo-sequence being correlated with a higher horizontal root fraction. However, this tendency had disappeared after 24 months.

Mahogany showed the highest shoot-root ratio and was significantly different from the others after 12 months. After 24 months, mahogany still had the highest shoot-root ratio at a stem diameter of 25 cm, but statistically seen, it was similar to sungkai and candle nut, and only different from sukun. For the stem diameter measured at 130 cm, there were no differences among the four tree species as to the shoot-root ration. However, sukun always tends to have the lowest shoot-root ratio. Sukun roots hence grow more vertically and faster than the other tree species. Relative to their root development, but also in an absolute sense, however, we can conclude that the aboveground growth of mahogany, sungkai and candle nut is faster than that of sukun. The topo-sequential position of the tree did not cause significant differences in shoot-root ratio. However, there is a tendency that the trees growing at the lower landscape position with presumably better water supply, have a higher shoot-root ratio.

Gini coefficients (g) and index of root shallowness of four tree species after 12 and 24 months can be seen in Table 5.2.

Table 5.2. Gini coefficient (g) and index of root shallowness of four tree species according to the topo-sequential position of the trees 12 and 24 months after planting. Values followed by different letters are significantly different (P<0.05) according to Duncan Multiple Range Test (DMRT), NS=no significant difference (P>0.05)

Treatments	Gini coefficient (g)		Index of root shallowness		
	12 months	24 months	12 months, d-25	24 months, d-25	24 months, d-130
Tree species					
Mahogany (M)	0.53^{ab}, n (16)	0.50^{ab}	0.16^{c}	0.61^{NS}	1.36^{NS}
Sungkai (Sa)	0.55^{a}, n (18)	0.77^{a}	0.31^{b}	0.76	1.27
Candle nut (K)	0.33^{b}, n (18)	0.61^{ab}	0.52^{a}	0.84	1.56
Sukun (Su)	0.52^{ab}, n (8)	0.35^{b}	0.21^{bc}	0.90	1.36
Tree position					
Top (T)	0.48^{ab}	0.62^{NS}	0.29^{NS}	0.81^{NS}	1.54^{NS}
Slope (S)	0.58^{a}	0.52	0.28	0.78	1.33
Valley (V)	0.39^{b}	0.52	0.33	0.75	1.30

A gini coefficient expresses the distribution of root sizes among all roots of a tree. At 12 months after planting, the numbers of sample trees (n) was not the same among the four tree species since most of the sukun trees observed had not enough roots to calculate the gini coefficient (≤ 5 roots per tree). The gini coefficients of mahogany, sungkai and sukun are statistically similar to each other after 12 months. For candle nut, the coefficients was significantly lower than in sungkai but similar to mahogany and sukun. After 24 months, the coefficient was still highest in sungkai, and similar to the coefficient in mahogany and candle nut, but different from sukun. Apparently, the candle nut trees produced many small roots at the early development (first year), followed by a year in which the number of the roots did not increase, but their size did, so the gini coefficient became higher. To the contrary, the sukun trees produced few big roots during the first year and a lot of small roots afterwards, so the gini coefficient became lower. Plate 5.2 illustrates the actual root distribution of the four tree species.

The topo-sequential position had affected the gini coefficients of the tree roots after the first year statistically significant, but this ceased later. It seems, that the trees in higher topo-sequential positions have more large-sized roots than those growing lower down.

5.3.3. Tree Biomass Estimation

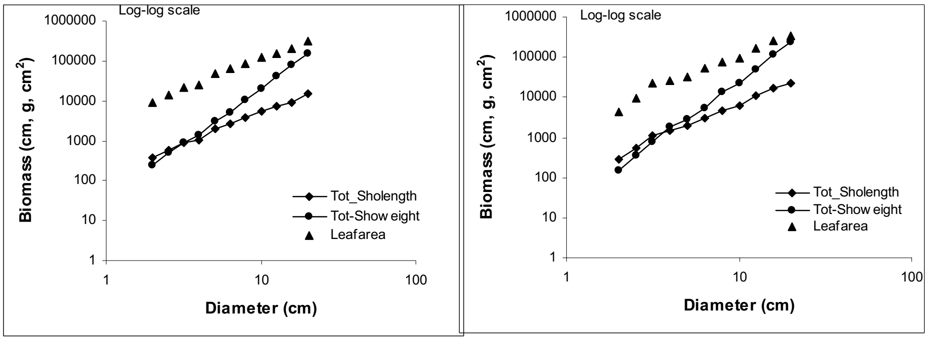
Several branching parameters have been calculated for each tree species. These parameters are based on an average value of minimum 50 branching points and were used as input data in the Functional Branching Analysis (FBA) software in order to obtain the aboveground biomass assessment of the trees. Table 5.3 contains the branching parameters and the other data concerning the four tree species.

Table 5.3. Branching parameters and other data of four tree species. N_{sub}=average number of branches; p=transfer coefficient; q=allocation coefficient; mean_p=average of p; mean_q=average of q; range_p=range between the maximum and the minimum of p to the mean_p; range_q=range between the maximum and the minimum of q to the mean _q; intercept=intercept of regression equation between diameter and length of links; slope=slope of the regression equation; range_l=relative range for links length; d_{min}=diameter of a link when branching stopped; d_{maxfin}=diameter of a link when leaf density maximum; $d_{zerofin}$=diameter of a link when leaf density zero; maxfindens=number of leaves per centimetre of links; SLA=specific leaf area

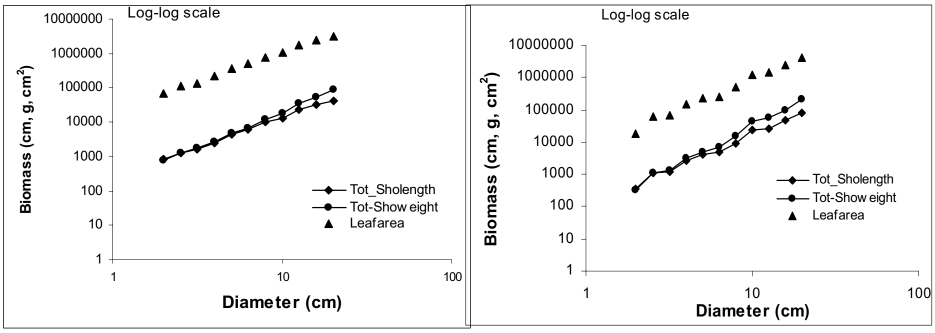
Parameters	Mahogany	Sungkai	Candle nut	Sukun	FBA's Default
n_sub	2.27	2.58	2.86	2.17	2.2
mean_p	1.34	1.18	1.25	0.99	1
mean_q	0.69	0.82	0.60	0.79	0.75
range_p	2.34	1.46	1.70	0.73	0.4
range_q	0.59	0.63	0.73	0.48	0.3
intercept (cm)	12.08	38.21	48.15	90.61	18
slope (cm)	25.31	5.39	9.55	-8.57	9
range_l	0.52	0.65	0.39	0.40	0.2
dmin (cm)	0.45	0.46	0.27	0.65	1
dmaxfin (cm)	0.87	0.60	1.07	1.54	0.42
dzerofin (cm)	4.24	4.60	4.72	4.72	0.84
maxfindens (cm^{-1})	0.56	0.54	1.32	0.38	0.5
SLA (m^{2}g^{-1})	75.9	110.8	97.1	74.0	95
average leaf area (cm^2)	74.5	81.1	327.4	1001.2	50
wood density (g cm^{-3})	0.488	0.371	0.276	0.275	0.7
branch density (g cm^{-3})	0.400	0.337	0.255	0.166	0.6
twig density (g cm^{-3})	0.340	0.123	0.170	0.060	0.5

The output of FBA software is the biomass of trees over a given range of diameters, either in absolute or as relative value, as well as the allometric equation between the tree diameter and respective biomass (length, weight or area). In the next paragraph, the biomass of the four tree species will be discussed.

The above-ground biomass of the four tree species is shown in Fig.5.5, over an interval of the diameter at breast height from 2 to 20 cm.



A. Mahogany B. Sungkai



C. Candle nut D. Sukun

Fig. 5.4. Relationship between stem diameter at breast height (d_{bh}) and above-ground biomass of the four tree species

The graphs of total shoot dry weight of mahogany and sungkai show a quite similar pattern. Starting at the lower level, they increase sharply, whereas for the candle nut, the graph starts at a higher level and increases slowly. The pattern of the biomass graph for sukun lies in between the former two. It starts at a low value and increases moderately. Therefore, for young trees, the total biomass of mahogany and sungkai is much below the total biomass of candle nut, whereas for mature trees, the biomass of mahogany and sungkai exceeds candle nut biomass. Table 5.4 presents the allometric equation, average diameter and total biomass of the four tree species grown in the first block of the agroforestry system established on the degraded alang-alang grassland, whereas Fig. 5.6 shows the dry weight of total biomass of those tree species.

Table 5.4. Average diameter and allometric equation of above-ground biomass per individual tree in four tree species at the first plot of the Agroforestry. Y is biomass of related variable and D is stem diameter at breast height

Parameters	Mahogany	Sungkai	Candle nut	Sukun
Diameter (cm)	4.340	4.994	7.994	3.212
Total shoot weight:				
- allometric equation	$Y=0.3385\ D^{2.795}$	$Y=0.01957\ D^{3.112}$	$Y=0.16822\ D^{2.074}$	$Y=0.06621D^{2.669}$
- dry weight (kg)	2.047	2.948	12.525	1.506
Total shoot length:				
- allometric equation	$Y=1.4109\ D^{1.560}$	$Y=1.0685\ D^{1.8094}$	$Y=2.4982\ D^{1.7435}$	$Y=1.0398\ D^{2.2165}$
- length (m)	13.94	19.61	93.67	13.81
Total leaf area:				
- allometric equation	$Y=0.3623\ D^{1.497}$	$Y=0.1907\ D^{1.7593}$	$Y=2.1498\ D^{1.7037}$	$Y=0.5829\ D^{2.2049}$
- leaf area (m^2)	3.262	3.229	74.206	7.638

The allometric equations for total shoot dry weight of mahogany and sungkai have a higher power than candle nut, so the increase of biomass dry weight of those tree species shows a much higher rate and proceeds faster than in candle nut trees. Sukun has a slightly lower power than mahogany and sungkai, but it starts at a much higher amount of biomass than those species, so its biomass is always higher until a diameter of 15 cm is reached (see Fig. 5.6). Sungkai biomass starts with the lowest amount, but it produces the highest amount at a diameter of 15 to 30 cm. When it reaches a diameter of 5 cm, it crosses the mahogany curve. At a diameter of less than 10 cm, candle nut is crossed, and at a diameter of 15 cm it crosses the curve of sukun. Candle nut, to the contrary, starts with the highest amount of biomass, but falls back to the lowest value at a diameter of 10 to 30 cm.

The above-ground biomass of the trees, as calculated with the allometric equations of FBA software did not fit precisely with the biomass amounts of those tree species obtained from the complete harvesting method. Slight differences were found for mahogany and sungkai, whereas for candle nut and sukun the differences were quite large (see Table 5.5). One possible cause might be that the relationship between diameter and length of the links was not proportional to biomass accumulation for candle nut and sukun trees. Usually, the bigger their diameter, the longer the length of the links. However, in the case of candle nut and sukun, it was found that several links with a larger diameter are shorter than other links with a smaller diameter. Fig.5.7 shows the graph of estimated biomass of four tree species based on the allometric equations as well as the harvesting method. Almost all the points obtained from the allometric equation lie above the points obtained from the harvesting method.

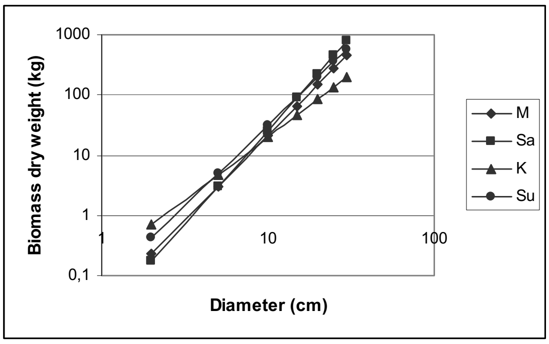


Fig.5.6. Dry weight of total above-ground biomass of the four tree species and the points where the curves cross each other. M=Mahogany, *Swietenia macrophylla*, Sa=Sungkai, *Peronema canescens*, K=Candle nut, *Aleurites moluccana*, and Su=Sukun, *Artocarpus altilis*.

Table 5.5. Comparison of shoot dry weight of the four tree species as calculated by the allometric equation of the FBA software, and biomass values obtained by the complete harvesting method

Tree species	Stem diameter (cm)	Shoot dry-weight (kg)		
		Allometric equation (A)	Harvested method (B)	A/B
Mahogany (1)	5.1	3.3	4.3	0.76
Mahogany (2)	5.3	3.5	4.4	0.80
Mahogany (3)	3.6	1.2	1.3	0.89
Average	**4.7**	**2.6**	**3.3**	**0.78**
Sungkai (1)	6.0	5.1	3.9	1.30
Sungkai (2)	5.0	2.9	1.7	1.66
Sungkai (3)	5.5	3.9	3.6	1.10
Sungkai (4)	6.4	6.3	3.7	1.69
Average	**5.7**	**4.6**	**3.0**	**1.45**
Candle nut	14.1	40.7	25.3	1.61
Sukun (1)	7.5	14.6	4.6	3.15
Sukun (2)	6.9	11.3	3.4	3.37
Sukun (3)	5.2	5.3	1.8	2.10
Average	**6.5**	**10.4**	**3.3**	**3.20**

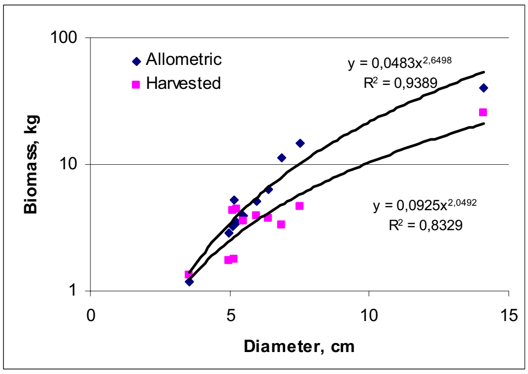


Fig.5.7. Above-ground biomass of the four tree species based on allometric equations and complete harvesting method.

5.4. DISCUSSION AND CONCLUSIONS

The distribution of nutrients, water and light, below and above the ground level among trees and annuals crops was influenced mainly by the characteristics of those tree species as components in an agroforestry system. Thin and narrow crown shapes of trees allow an optimal transmission of light for the crops beneath. Deep and vertical roots of trees enable those roots to absorb nutrients in deeper zones and to function as safety net as well (Suprayogo et al., 2002). By these tree characteristics, distribution of resources among trees and crops would be optimal both for ecosystem balance and for agricultural purposes. However, pioneer tree species, fast growing and drought tolerant, that may be adapted to stressed environments, such as degraded alang-alang grassland, usually have opposite characteristics in the matter of the crown shape and root distribution. Van Noordwijk et al. (1996), reported that trees with a well-developed tap root and few lateral roots extending in the top soil generally have a slow initial growth. The notion of fast growing and 'non-competitive trees' may be a contradiction in terms, at least where the initial establishment phase is concerned.

Our field experience points out that timber tree species have a narrower and thinner crown shape during early stage of their life compared with multipurpose trees or fruit tree species. They also often have deeper and vertical roots. The detailed root observation and measurement in the present study showed that mahogany and sungkai, during their first two years, have a lower shallowness index of the roots and a higher shoot-root ratio than candle nut trees. Candle nut trees have more lateral and superficial roots, which spread out beyond its crown projection on the ground, notwithstanding their dense and wide hemispherical crowns. They capture more light than mahogany and sunkai, with their paraboloid crowns. The trees grow fast and produce fruits after two to three years. A few of the candle nut trees, planted and observed in this study already started to yield some fruits, particularly in the first and third block (Plate 5.1E).

Indeed, candle nut trees have several strong points when growing on degraded alang-alang lands. They cast enough shade to reduce the above-ground biomass of alang-alang, as well as to prevent recovery of the grass because the regeneration capacity of the rhizome is reduced too. The trees also contribute significantly to the farmer income, because they start fruiting when still young, in the first two or three years. However, this tree species dominates the root zone by forming horizontal, lateral and superficial, roots. In this circumstance, inter-cropping may lead to unbalanced distribution of resources, nutrients, water and light, among trees and annual crops. However, the problem of limited light reaching the lower stratum, can be solved by introducing shade tolerant crops such as ginger, coffee, or cacao.

Trees growing lower down on a toposequence have a higher shoot-root ratio. In the valley, soils are often rich in nutrients and water. In the rich soil fertility, tree roots absorb nutrients and water easier. In such a case, it is not necessary to accumulate photosynthates to promote new adventitious roots. Most of the photosynthates were accumulated in above-ground parts of the tree, and so the shoot-root ratio became higher. An opposite scenario may have occurred in the trees growing higher up along the toposequence.

The relationship between stem diameter and above-ground biomass, especially shoot weight of the four tree species points to a different pattern. Mahogany and sungkai as timber trees have a lower level of biomass during the initial establishment phase. Further, they displayed higher growth rates and a much higher shoot weight than non-timber trees at the same stem diameter. Multipurpose tree species, on the contrary, mainly candle nut, established their biomass at the higher level during initial growth, but the growth rate of the shoot weight was much lower. These differences imply that timber trees can be easier integrated with annual crops in order to achieve a balanced distribution of resources, at least during the early establishment phase. However, no farmer income can be generated by these tree species, except high quality wood at the end of the rotation.

Implementing Functional Branching Analysis (FBA) software to predict a tree biomass, mainly above the ground, is proven to be easier than other methods, and non-destructive. In the present study, so far, its biomass above ground could be estimated for timber tree species (mahogany and sungkai). For multipurpose tree species, however, mainly for sukun trees, this software leads to strong over-estimation. The relationship between diameter and length of several links may be different from the assumptions in FBA, because these trees show early reiteration, which lowers their overall h/d ratio (Oldeman, 1990). A short and slender axis (link) then may stop its extension growth, for instance because other branches or reiterated crownlets take over, but at the same time they may increase its diameter growth because much sap has to be transported. So, the short and slender axis becomes a short and thick axis.

The allometric equations for predicting above-ground tree biomass used in this FBA software was $Y=aD^b$, where Y is tree biomass and D is stem diameter at breast height, a and b are intercept and slope (power) of the regression, respectively. To reduce uncertainty in the use of the allometric equations, Ketterings et al. (2001), proposed to estimate the ‘b’ parameter from site-specific relationship between height

(H) and diameter (D), which agrees with Oldeman's findings mentioned above. The parameter 'a' should be estimated from the average wood density (ρ) at the site as a=rρ, where r is expected to be relatively stable across sites.

Several conclusions can be drawn from this chapter:

- Mahogany and sungkai have a physiognomic crown shape and a root distribution that might serve optimally in the establishment of an agroforestry system, because they are particularly apt to live together with annual plants. Candle nut, however, is more appropriate to reduce *Imperata cylindrica* (alang-alang) grass by shading with its wide, dense hemispherical crown.
- Timber and multipurpose tree species have different growth rates and rhythms of above-ground biomass. During the early establishment phase, timber tree species have a lower above-ground biomass than multipurpose tree species.
- Functional Branching Analysis (FBA) software can estimate above ground biomass of mahogany and sungkai with an average standard deviation of 1 ± 0.34. This software should be corrected in order to accommodate biomass more precisely in the case of trees with other temperaments and particularly, with early and profuse reiteration.

6. GENERAL DISCUSSION AND CONCLUSIONS

6.1. DEVELOPMENT OF AN AGROFORESTRY SYSTEM ON *Imperata cylindrica* GRASSLANDS BY SMALLHOLDER FARMERS

The preceding chapters addressed a number of ‘necessary’ conditions for development of a smallholder agroforestry system on *Imperata cylindrica* grasslands in East Kalimantan, but in no way can we claim that these are ‘sufficient’ conditions to expect a large-scale spontaneous adoption of these methods, as our interactions with farmers, reported in chapter IV have shown. The necessary conditions that we did establish are:

1. Trees can be found that are compatible with the low fertility status of the sites and that meet farmers’ preferences for fruit, pole or timber production, and that can be raised in nurseries within reach of the farmers.
2. These trees will develop adequate mycorrhizal relationships, either with fungi present in the grassland ecosystem an/or with fungi provided as inoculum in the nursery stage.
3. Relatively simple methods exist that initially overcome ‘alang-alang as a weed’ and are within the financial and labour-supply reach of smallholders.
4. Inter-cropping with food crops is feasible in the early years to make use of fertilisers, from which the trees will also benefit, feasible and replace the competitive alang-alang by less-competitive crops.

Other essential conditions on which this research did barely touch are:

5. Community-level motivation and actions can be built to control free-ranging fires in the *Imperata cylindrica*-dominated landscape.
6. The agroforestation has to provide ‘returns to labour’ that are competitive, in the farmers’ perception and at the ‘discount rate’, that they use in these evaluations, with the alternatives present: daily paid jobs in the legal and illegal logging enterprises of the area and other forest operations, ‘off-farm’ agricultural activities on state forest land or non-agricultural and non-forestry jobs.
7. The farmers have access to credit sources to overcome the ‘waiting period’ between labour investment in perennial (tree) crops and the time at which these trees contribute to actual income.
8. Ways can be found to bridge the ‘forest ecologist’, ‘state forest manager’, ‘smallholder agroforester’, ‘local government’ and ‘environmental service provider’ perspectives. Those have expressed strong opinions about the desirability and perspectives for smallholder agroforestation of degraded lands in the past, to a joint analysis of the incentives that will be required to achieve common goals.

This general discussion will focus on technical results on requirements of 1 to 4 and then return to a brief discussion on requirements of 5 to 8 on the basis of experience obtained in the Semoi villages.

6.2. CHOICE OF TREE SPECIES AND SITE DIFFERENCES WITHIN THE *Imperata cylindrica* DOMAIN

Discussions with farmers in the area indicated that they prefer to plant teak (*Tectona grandis*), mahogany (*Swietenia macrophylla*) and 'sungkai' (*Peronema canescens*) as timber tree species; 'durian'(*Durio zibethinus*), candle nut (*Aleurites moluccana*) and 'sukun' (*Artocarpus altilis*) as multipurpose or fruit tree species (see chapter 2). Their main reasons for this preference are high quality of wood and fruits.

In our search for tree species that meet this expectation and are compatible with the site conditions, we were clearly successful in three of the four species tested. The experiments showed that sukun had a relatively low survival rate and showed large differences in growth rate of the trees that survived the transplanting. In follow up research, not reported here in detail, we have tried to identify the soil or site factors that govern the success or failure when candle nut is planted across a range of microsites within the alang-alang grassland domain of Semoi. We found only a weak correlation between the tree performance in a pot trial with soil obtained from 18 microsites across the landscape, and tree growth when planted at these 18 sites. The correlation declined with the age of the tree, suggesting that the chemical fertility (that is conserved in the pot trial) is less important than the site factors that govern water supply and/or biological factors, that are not conserved in a pot trial with regular watering. For sukun and trees of similar requirements, a more detailed stratification of the alang-alang grassland domain will be needed, to increase the rate of success of planting. The 'index of site quality' introduced in chapter 2 tries to fulfils this need, and it correctly identified 'the first block' of the experiment as among the 'best' sites, the third block was moderate and the second block was the poorest site.

Variation of tree performance grown in the three separate blocks was higher than variation of that among the treatments. The experimental design used was the split-plot block randomised design due to our assumption that the three blocks were heterogeneous and might represent different 'strata' of the overall domain of 'alang-alang grassland' sites. This assumption was conformed by the variation in tree performance of the four tree species among the blocks.

Tree performance consistently followed the site quality clustered. The tree performance in the first block was superior because that block was considered as the most hospitable site for plants to grow, due to the richness of its soil. The tree performances in the third and second block were considered as moderate and poor, respectively. Besides, the four tree species differed in sensitivity to those site qualities. Mahogany and sungkai grew well in the first and third block, and even in the second block they still showed 'average' growth rates. However, candle nut and sukun showed the normal growth in the first and third blocks only. In the second block these two tree species grew very poorly, except in a small part of the area, where fern was absent.

This variability among the blocks may be related to the sites' history. The second block indeed showed typical giant podsol features of the previous *Shorea laevis* ('bangkirai') stand on the area. The soil was much leached, possibly because of the

S. laevis litter and roots. The abundance of ferns in this block was also an indication of the differences in the soil properties. Local people judged that almost all soils having been previously under 'bangkirai' stand show poor soil properties and abundance ferns. In addition, their texture is predominantly sandy and in extreme conditions those soils are almost entirely composed by white sands, such as in the third block of the development research (Sumardi's farm). On the contrary, soils that were previously under *Eusideroxylon zwageri* ('ulin or iron wood') are locally considered as rich soils and are usually occupied by alang-alang only, without ferns. The soils of the other two blocks, the first and the third blocks, previously occupied by the *E. zwageri* stand, were considered as rich soils and their texture were dominated by clay and loam.

The Functional Branching Analysis (FBA) software that was tested for its ability to predict above-ground tree biomass was proven to be an easy to use and non-destructive method. However, so far, its performance for the timber tree species, in this present study, mahogany and sungkai was clearly better than that for the multipurpose or fruit trees with a broader crown. Especially for sukun trees, this software leads to a strong overestimation of the amount biomass and further investigations will be needed to redress this problem.

6.3. MYCORRHIZAL ASSOCIATION: IS INOCULATION WORTHWHILE OR EVEN ESSENTIAL?

The role of mycorrhizal fungi in growing plants is beyond doubt. It is well know that mycorrhizal networks in root systems of plant communities not only increase the access of plants to nutrients and water but also protect the plants from pathogenic micro-organisms and perform still other ecological and physiological functions (Oldeman, 1990; Smith and Read, 1997). Most plants form mycorrhizal associations and almost all soils contain a wide diversity of spore types of mycorrhizae (Smith and Read, 1997; Setiadi, 1996, 1999; Onguene, 2000). The fact of this highly complex ecological network in the initial situation should be taken as a point of departure to decide whether or not inoculation of mycorrhizal is useful or even necessary to promote tree growth in a given environment. For certain type of trees and a certain type of soil conditions, tree seedlings may have difficulties in establishing adequate mycorrhizal partnerships. Inoculation of trees in the nursery stage can be a matter of life or death for the young trees and have strong effects on subsequent growth of the young trees and hence on the success from the tree planters' point of view. Following on to the earlier research in East Kalimantan by Smits (1994), who demonstrated that the ectomycorrhizal associations on which most Dipterocarp trees depend virtually on inoculation in the nursery stage for successful planting, this research focussed on the needs of a range of other trees for inoculation with arbuscular mycorrhiza fungi.

Onguene (2000) reported that in disturbed areas, e.g. logged-over forests and fields under shifting cultivation, spore numbers and root colonisation were on the decline. Setiadi (1999) and our present studies indicated that there were abundant spore types of arbuscular mycorrhizal fungi in alang-alang grasslands, so these are no ecological equivalents of disturbed areas.

Inoculation of tree seedlings in the nursery was followed by a small positive effect in promoting initial survival, but no promotion of subsequent tree growth in the alang-alang grasslands of our test sites. Inoculation increased survival rates of transplantation into acid soils with poor nutrient supply, by 6.5% as an average for the four tree species, with virtually nearly zero effect on sungkai and candle nut, and it increased 5% for mahogany and 16% for sukun. The positive effect on the survival rate was not linked to the absolute chance of success of planting: the species with the highest (mahogany at 95%) and lowest (sukun at 69%) survival rates both showed positive effects of inoculation, while the trees with intermediate survival rates (sungkai and candle nut) did not. Subsequent growth of trees that survived during the critical early stage was not affected by the mycorrhizae inoculated upon the trees in the nursery for any of the species tested. Hence, a decision whether to inoculate tree seedlings or not should be based on a thorough site exploration and assessment of the mycorrhizal inoculum potential in the areas to be reafforested. However, soils with a high proper mycorrhizal inoculum potential are not always the most effective in enhancing plant growth (Asbjornsen and Montagnini, 1994 *ex* Onguene, 2000). Site exploration should be addressed to main factors limiting tree growth and the potential of external mycorrhizal inoculation to overcome those limiting factors, as well as the capacity of newly introduced fungal strains or species to survive under the soil conditions of the site in interaction with native strains or species. Dodd and Thomson (1994) designed a strategy chart (Fig.6.1, modified), of how to reach a decision to apply mycorrhizal inoculation or not to overcome factors limiting tree growth in a certain site. In alang-alang areas, with their high levels of indigenous mycorrhizal inoculum potential should in the first place be investigated as to their effectiveness in increasing tree growth. If effective, inoculating tree seedlings with mycorrhizal fungi in the nursery is unlikely to increase tree growth in the field.

Our present study indicates that the mycorrhizal inoculum potential of the *Imperata cylindrica* grasslands tested was sufficient and in this condition there is no compelling need for the use of externally acquired inoculum of the type used, in the nursery unless the inoculum is readily available at very low cost. Hence, in the alang-alang grassland with abundant indigenous mycorrhizal fungi, management options that maintain and even increase colonisation of the indigenous mycorrhizal fungi should be implemented.

The management might increase plant diversity, including nitrogen-fixing plants, as a way of stimulating the survival of a broad array of mycorrhizal strains/species.

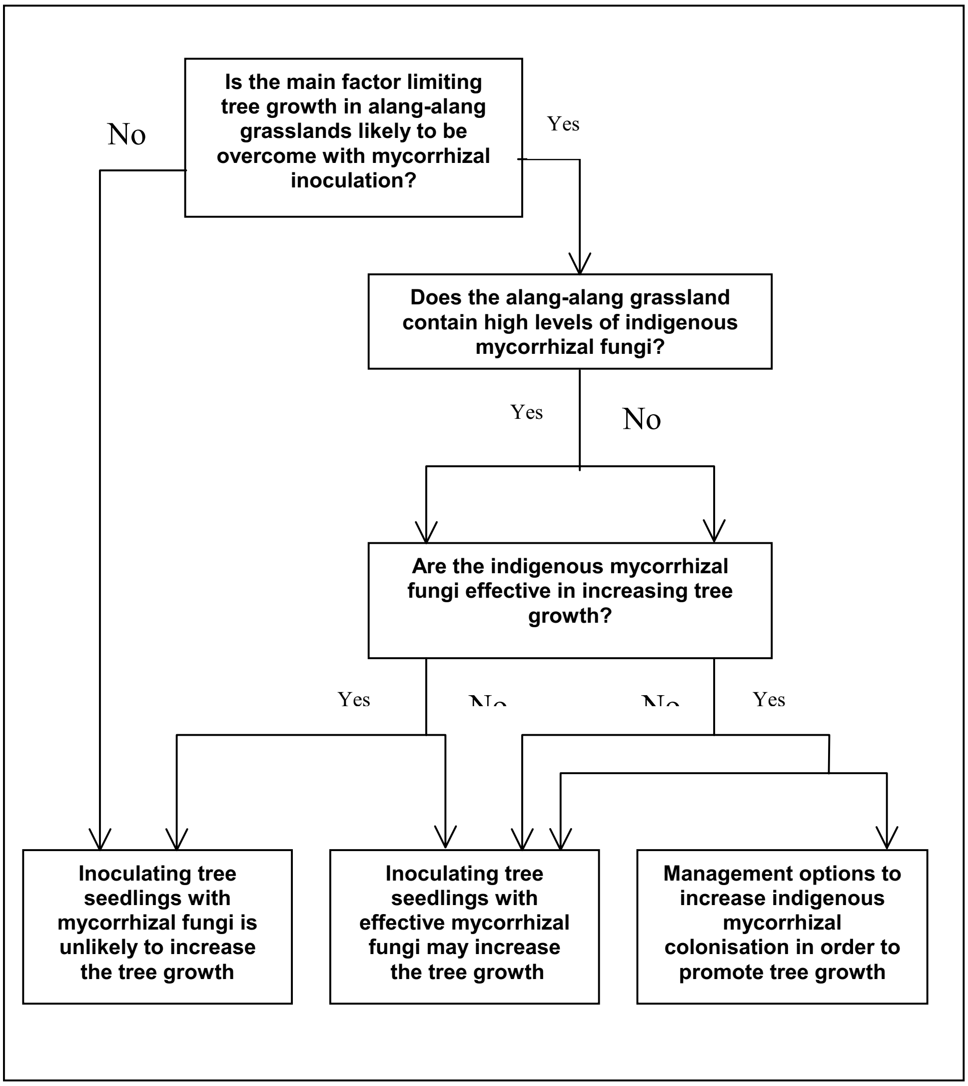


Fig. 6.1. Strategy to decide on the necessity of mycorrhizal inoculation (after Dodd and Thomson, 1994; modified).

The presence of rhizosphere bacteria on root systems of nitrogen fixing-plants can stimulate germ-tube growth of VA mycorrhizal fungi (Azcon and Mosse *ex* Kapulnik and Douds, 2000). Interactions between *Glomus mosseae* and *Rhizobium* improved nitrogen and phosphorus accumulation in plants (Toro et al. *ex* Kapulnik and Douds, 2000). Increasing plant diversity is expected to lead to increased mycorrhizal diversity and colonisation and in its turn will contribute to growth of plants immigrating into the alang-alang grassland.

6.4. ALANG-ALANG ECOSYSTEM CONVERSION INTO AN AGROFORESTRY ECOSYSTEM

Although chapter 3 showed that different methods to reduce the ecological role of *I. cylindrica* did not lead to significantly affect the growth of the four tree species, these methods bring about significant differences in the post-treatment biomass of the alang-alang itself, described in chapter 4. The implications of these findings probably depend on the management package that will be applied. For tree crop gardens or reforestation programmes, where annual or agricultural crops are not included in the system, the pressing method may be sufficient to allow tree growth at a normal level. However, a nitrogen-fixing legume cover crop has to be incorporated in the systems. The success of the relatively simple 'pressing' method may have depended on a critical way on this cover crop to smother the regrowth of alang-alang plants that had not been killed by the pressing alone. When a complex agroforestry system with several agricultural crops and tree species would be developed, spraying with herbicide or ploughing should be implemented in order to reduce the alang-alang biomass to a minimum level before the seeds of a nitrogen fixing cover crop were sown.

6.5. INTER-CROPPING

Incorporation of the biomass of the cover crop *Pueraria javanica* planted in the study sites into the soil improved nitrogen and carbon organic content of the soils significantly. Nitrogen contents more than doubled, from 0.07 % at the initial condition to 0.16 % at 24 months after the establishment of the agroforestry plots. However, this amount was not enough as yet to enrich the nitrogen content of the soil to the normal level. The normal or moderate nitrogen level of mineral soils ranges between 0.2 and 0.5 % (PPT, 1997). The significant differences of the corn yields between fertilised and unfertilised plots, either in the first or in the third block of the experiment, support these values of nitrogen content. Nitrogen content in these soils indeed still acts as a limiting factor in increasing of corn yield, since the normal content was not achieve yet. By application of chicken manure with a dosage of 2 Mg ha^{-1} and NPK compound (15-15-15) fertiliser with a dosage of 100 kg ha^{-1}, corn yield increased significantly compared with unfertilised subplots in the first block. In the third block, plants fertilised with organic manure produced significantly higher grain dry weight of the corn compared with unfertilised plants at the first season. At the second season, the corn yield increased sharply compared with the corn yield at the first season, since in-organic (N and P) fertilisers were also applied in the second season. By allowing the cover crop to grow a bit longer, it can therefore be estimated that the normal nitrogen content will be reached and that nitrogen will not act as a limiting factor for agricultural crops anymore. The organic carbon contents of the soils increased too. However, the augmentation was only of 13%, as compared with the initial condition of the experiment. As the success of the food crops will critically depend on fertilisation of the site and may provide the economic incentive to do so, we can expect the trees to benefit in the longer run, based on their ‘safety net’ role demonstrated in trials in Lampung (Suprayogo et al., 2002; Van Noordwijk and Cadisch, 2002).

Inter-cropped corn yields were significantly affected by tree shading both in the first and the third blocks. Corn yields did not reach their maximal potential production under an overall tree-LAI higher than one and/or under overall tree-shading of more than 40%. This tightly correlated with photosynthetic characteristics of the corn. It belongs to the plants with C4 photosynthetic pathway, and so are well adapted to the hot open climatic conditions in tropical countries. This plant is more efficient in using highly intensive light radiation compared with C3 plants, because the photosynthetic curve of C4 in practice has no asymptote. It means also, that photosynthesis of C4 plants is reduced sharper by a drop to certain, lower degrees of light radiation than photosynthesis of C3 plants. Therefore, the corn yield dropped when light intensity was reduced to the level of 60% of full sun radiation. However, an increase in nutrient supply, by applying fertilisers, appeared to increase the corn yield at the same shade level. This indicates that the tree-soil-crop interaction may be nutrient-based rather than being a simple shading effect on photosynthesis. Once more, the system proves its complexity in which all biotic factors are interdependent. Further, experiments may be needed to clarify the above- and below-ground aspects in this interaction, and forms of tree root pruning that limit below-ground interaction for the same level of shading may be effective (Van Noordwijk et al., 1996).

Selection of tree species that can be well integrated in the design of agroforestry systems has to meet conflicting requirements. On one hand, a dense and broad canopy, fast growth, and drought tolerance characterise pioneer tree species, that adapted to stressed environments, such as alang-alang grasslands. Such species also provide optimal shading to prevent regrowth of alang-alang. On the other hand, such characteristics of trees do not allow a balanced distribution of resources (light, nutrient and water) among trees and crops as components of the agroforestry system. Below the ground, this is roughly similar. Tree species with the above characteristics often also have many lateral and superficial roots in the topsoil, which lay over the root systems of annual crops. If on the contrary, trees with thin and narrow crowns, moderate growth rate and a well-developed tap root systems are chosen, these would provide a balanced distribution of resources among the trees and crops. However, the capabilities of such trees to prevent re-growth of alang-alang are not optimal for eco-transformation purposes. If the conversion of alang-alang grassland into more productive and sustainable land use is the main objective, it is suggested to establish an agroforestry system by using pioneer tree species. These tree species, multipurpose or fruit tree species, with more umbrella crown shape may reach the adequate shade for *I. cylindrica* control where light intensities at ground level have to be reduced to less than 20% of full sun light (Purnomosidhi et al., in press). However, these light levels are too low for light-demanding food crops like corn as discussed above. Therefore, the shade-tolerant crops should be introduced in the period of full shade-based control of alang-alang.

On the basis of the current texture and vegetation in the alang-alang phase, farmers may be able to recognise the previous forest type, and current site quality. For the ‘ulin’ sites all four tree species, the timber as well as the fruit trees, that we tested are suitable, and inter-cropping with food crops may be appropriate. The timber trees will allow for a longer period of inter-cropping than the more spreading canopies of the fruit trees, but may also depend more critically on such inter-cropping practices, as they will not easily 'shade out' the grass. For the 'bangkirai' sites, only the timber trees mahogany and sungkai can be recommended and inter-cropping with food crops is unlikely to be an attractive option.

6.6. OTHER REQUIREMENTS AND PERSPECTIVES ON AGROFORESTATION OF *Imperata cylindrica* GRASSLANDS

The ***'forest ecologists'*** view is that the alang-alang ecosystems can be considered as a blocked phase in ecological succession and as such requires specific intervention to break open the cycle. Blocked phases, as shown in the introduction, are not necessarily degraded or poor biological communities. In order to depart rapidly from such phases, human interference may lead to increasingly complex interactions among the existing and the newly introduced components. In this way, a new complex ecosystem can be built in the area, as a replacement of the alang-alang environment. Agroforestry ecosystems as complex ecosystems contribute to increased land productivity and sustainability. Agroforestry systems are dynamic, mixed land use systems harmonising ecology and economics. They combine perennial trees and agricultural crops in a multi-storied vegetation structure, simultaneously and/or sequentially (Oldeman, 1983; Nair, 1993 *ex* Van Noordwijk and Tomich, 1995).

For the ***managers of the 'forest estate'*** establishment of agroforestry systems as a substitute for useless alang-alang ecosystems was considered to be a suitable land use option, particularly in settlements surrounded by forest areas, like in transmigration villages in East Kalimantan. Indrabudi (2002) studied the planning implications of such shifts in land use in a comparable setting in South Kalimantan. By establishment of agroforestry systems in such areas, it is expected that the villagers earn a sufficient income from their own land, this being a viable alternative for the people who currently enter the surrounding forest areas to practice shifting cultivation or product extraction for their livelihood. The same operation allows the conservation of natural forest resources. Murniati et al. (2001) reported that the agroforestry "mixed-gardens" contributed to the reduction of farmers' dependence on the resources of adjacent Kerinci Seblat National Parks in Sumatera. Households that lived from mixed gardens exclusively gathered a lower income from forest products gathered inside the park as compared with households that mainly lived from wetland rice-fields. Those households that had farms composed both of wetland rice fields and mixed gardens, had a dramatically lower degree of economic dependency on park resources than households in either of the other two categories.

For the **smallholder-agroforester** the 'participation by the local community' has to be seen from the perspectives of livelihood strategies of the households, the labour, land and other resources available and the various options available to use these resources. From the evidence at hand, the 'agroforestation' option

> is technically feasible, at least on the better ('ulin') sites, but can not compete in its immediate 'returns to labour'.
>
> From an **'environmental service'** perspective, smallholder agroforestation may be a cost effective way of reducing fire risks and increase C stocks in the landscape, that justify a certain level of public spending on incentives (at the minimum: spread of technical information, and subsidy of tree nurseries). The expectation that such incentives by themselves will stop 'forest encroachment' are, however, naive at best.

Did the present study resolve all the remaining problems in transforming useless but strong alang-alang ecosystems into useful and sustainable agroforestry ecosystems? Of course it did not. However, it contributed with a few realistic recommendations which will operationally improve such conversions in practice, for instance the method of weakening the grass or the tree species choice most suited to both the management aims and ecosystem dynamics close to nature. It contributed also a valuable general insight, which is the fundamental image of an agroforestry field or farm as a system of formidable complexity and for this reason, without clear-cut and simple recipes for universal remedial actions for specific problems. In agroforestry, cooking books are impossible, because the recipes would change both with the objectives of the farmer and the diversity of the site and biological community.

This image is supported by all studies in the series of which the present study is one, by Smits (1994), Yasman (1995), Hatta (1999), Indrabudi (2002), Omon (2002), and Aldrianto (2002). Most of these studies were part of the Indonesian-Dutch programme Hutan Lestari International, initiated by the former Minister of Forestry, Djamaluddin Suryohadikusumo.

Plate 2.1. Satellite image of Balikpapan and the surrounding areas. Landsat 7 ETM, December 2000. ○ = Semoi II village, ∆ = Semoi III village

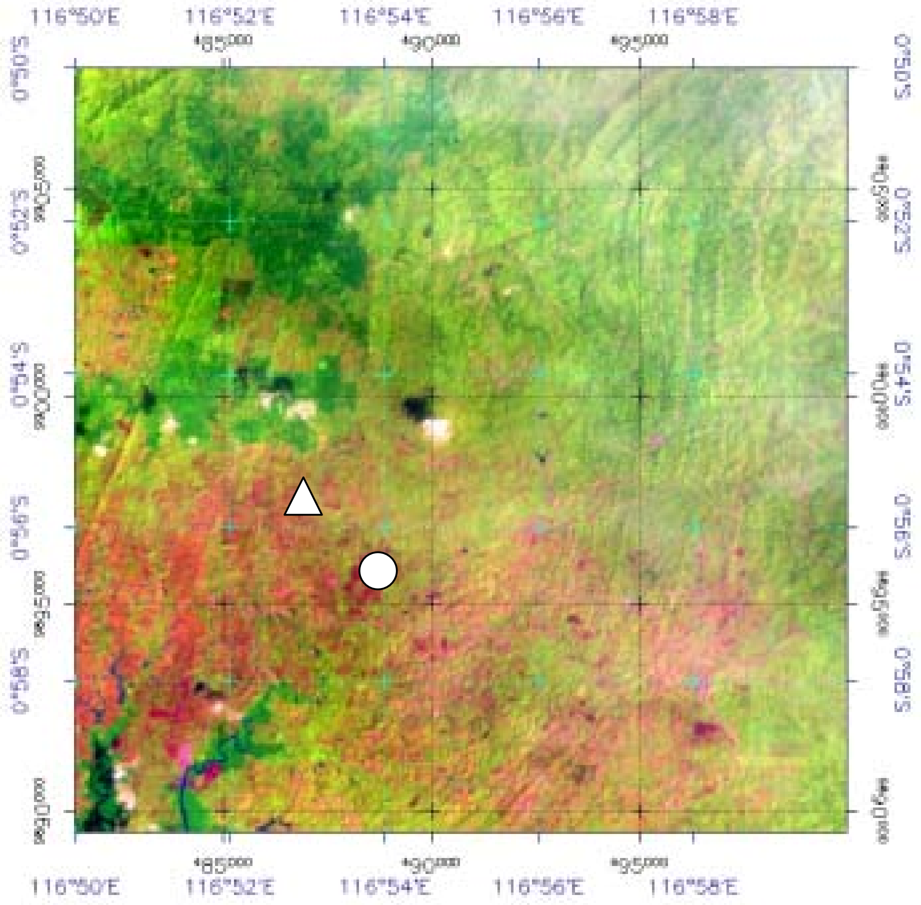


Plate 2.2. Satellite image of Semoi II and Semoi III areas (located between 0°55' S Latitude, 116° 52' E Longitude and 0° 57' S Latitude, 116° 54' E Longitude). Landsat 7 ETM, December 2000.
O = Semoi II village, Δ = Semoi III village

A

Plate 2.3. Initial condition of vegetation in three blocks of the main research.

A. Block I,
B. Block II,
C. Block III.

Note the variation in tophographical relief

B

C

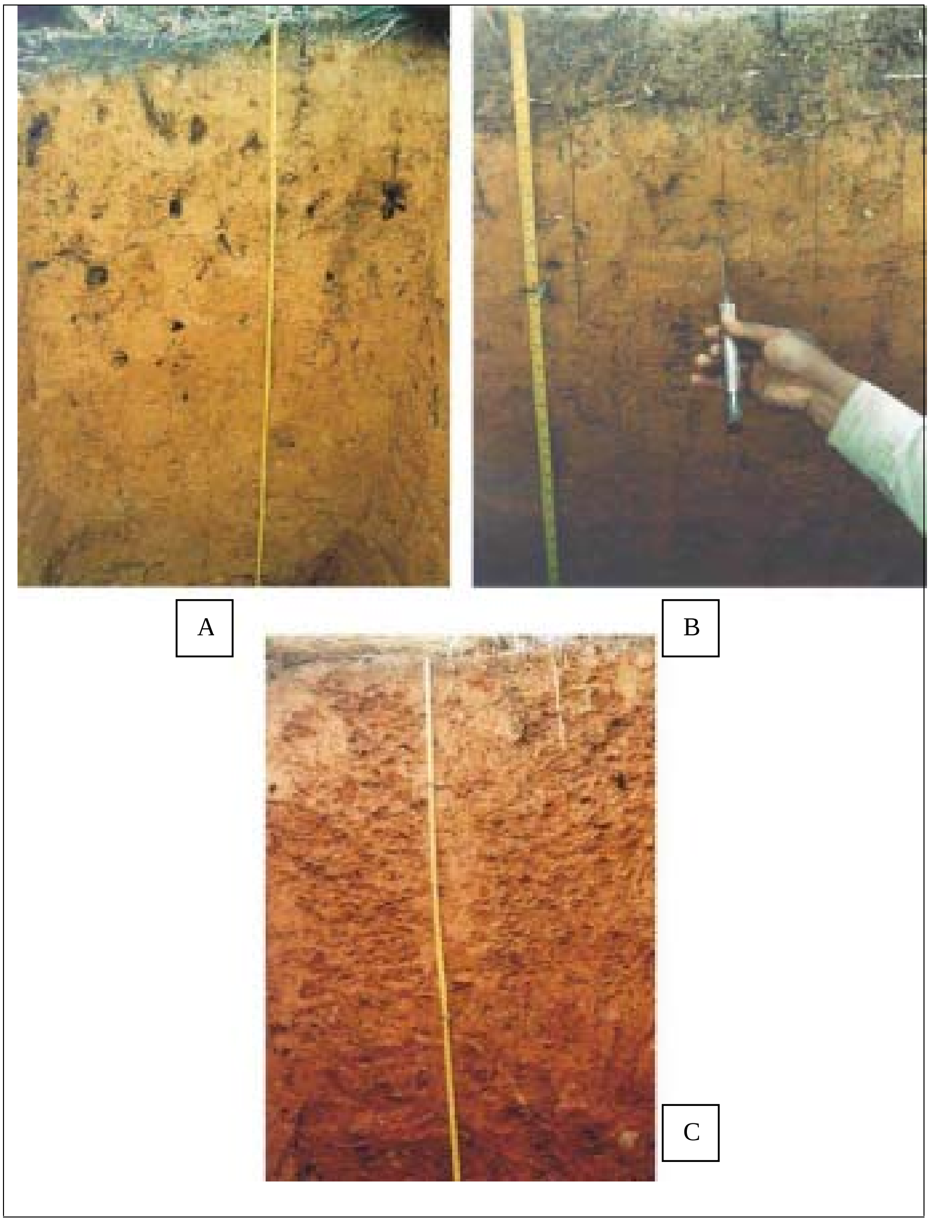


Plate. 2.4. Soil profiles of the research sites. A. Block I, B. Block II and C. Block III

Plate 4.1. *Pueraria javanica* dominating land surfaces in the first block, 12 months after planting

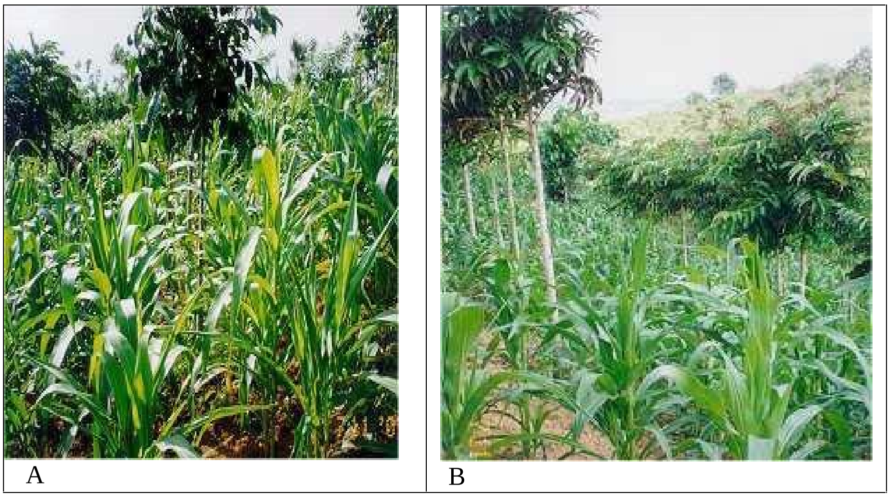


Plate 4.3. Inter-cropping between corn and mahogany trees (A) and sungkai trees (B), in the third block

Plate 4.2. Growth of the corn under several tree species in the Block I. A. One month after planting, with (in foreground) and without fertiliser (background). B. Five weeks after planting, C. Eight weeks after planting, fertilised (in foreground) and not fertilised (background)

Plate 5.1. Morphological expression of the four tree species. A. Mahogany (*Swietenia macrophylla* King, Meliaceae); B. Sungkai (*Peronema canescens* Jack., Verbenaceae); C. Candle nut (*Aleurites moluccana* Willd., Euphorbiaceae); D. Sukun (*Artocarpus altilis* Fosberg, Moraceae); E. Candle nut, mature stage and F. Sukun, mature stage.

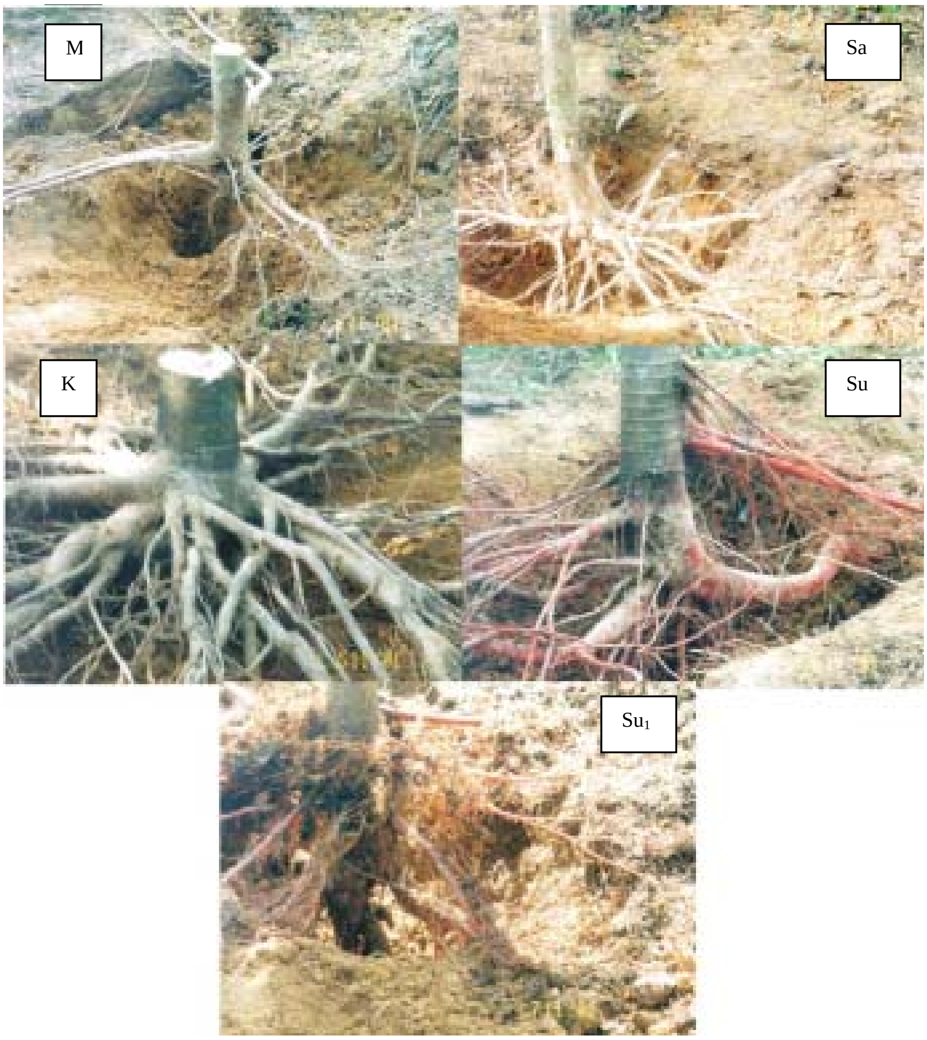


Plate 5.2. Actual root distribution according to their direction and size of four tree species. M=mahogany, *Swietenia macrophylla*; Sa=sungkai, *Peronema canescens*; K=candle nut, *Aleurites molucana*; Su=sukun, *Artocarpus altilis*; and Su$_1$=sukun, *A.altilis*, with very big vertical roots.

SUMMARY

The thesis “From *Imperata cylindrica* grasslands to productive agroforestry” deals with technical options for the conversion of an *Imperata cylindrica* (alang-alang) grassland ecosystem into a productive agroforestry ecosystem that can be used by smallholder agroforester/farmers. The research reported here deals with a number of necessary conditions for such a conversion: 1) finding trees that are compatible with the low fertility status of the sites and that meet farmers’ preferences for fruit, pole or timber production, and that the seedlings can be raised in nurseries within reach of the farmers; 2) ensuring that these trees will develop adequate mycorrhizal relationships, either with fungi present in the grassland ecosystem and/or with fungi provided as inoculum in the nursery stage; 3) identifying relatively simple methods to overcome the ‘alang-alang as a weed’ aspect and are within the financial and labour-supply reach of smallholders, and 4) testing the feasibility of inter-cropping with food crops in the early years to make use of fertilisers, from which the trees will also benefit, and provide products and benefits in the early phase of the system, justifying the labour investment into the conversion. Beyond these technical requirements, a number of other ‘essential conditions’ have been identified that have to be met before we can expect widespread and spontaneous adoption of these conversion methods, but the thesis and research project focussed on these four aspects.

The research took place in the neighbourhood of the Wanariset I Research Station, located some 38 kilometres to the northeast of Balikpapan, East Kalimantan, Indonesia. The field experiments were located in a transmigration area, some 20 to 27 kilometres to the northwest of the Wanariset I Research Station. The nursery experiment and seedlings preparations were conducted in the Wanariset I Research Station itself.

The thesis consists of six chapters. The first chapter provides a general introduction with a literature review on *I. cylindrica*, its identity and behaviour as a species and as a dominant grasslands component. The various perspectives: poor soil indicator, degraded forest, blocked successional stage, wasteland, opportunity for carbon sequestration projects, opportunity for rehabilitation to take pressure off the remaining forests, expressed in the literature. Based on past experience at the Wanariset station with a clearly identified need for mycorrhizal inoculation of Dipterocarp trees, literature on mycorrhizae (ecto- as well as arbuscular mycorrhizae) is reviewed in the context of agroforestry systems and reforestation technologies. Besides, this part of the book defines the scientific and practical problems, it formulates the study and outlines the research objectives.

Chapter 2 describes the research sites in details, according to both their biophysical and socio-economic characteristics. A base line survey conducted in the area showed that nearly 50% of community income is derived from the forest activities, e.g. illegal cutting. For this reason, the abundance of abandoned alang-alang grasslands and the scarcity of farms in the villages made these sites into an excellent object of research for technical aspects of converting alang-alang grassland into more productive land use. However, the objective to provide the community with a form

of agricultural land use that can provide them with a competitive on-farm income provided a tall order.

Chapter 3 reports the growth of four selected tree species in the alang-alang grassland environment and tested the need for inoculation with mycorrhizal fungi in the nursery as a way to promote tree growth in the field sites. In the nursery, inoculation with mycorrhizal fungi (resting spores in 'Mycofer' belonging to *Glomus manihotis*, *Glomus etunicatum*, *Gigaspora rosea* dan *Acaulospora tuberculata*) did not promote seedling growth. Inoculation in this phase of cultivation led to a statistically significant increase in survival rate of trees, once they were transplanted to the field. However, the average survival rate of the four tree species increased by 6.5% only. Nursery inoculation of trees did not have any positive effect on the subsequent growth of those trees that survived the critical early stage. Our data show no compelling need for the use of the inoculum of the type used in the nursery. The inoculum potential of these *I. cylindrica* grasslands for trees depending on arbuscular mycorrhizae was apparently sufficient.

The performance of four selected tree species growing in the alang-alang grassland, and their capability to outshade the grass, mahogany (*Swietenia macrophylla* King, Meliaceae), sungkai (*Peronema canescens* Jack., Verbenaceae) and candle nut (*Aleurites moluccana* (L.) Willd., Euphorbiaceae) made them most suitable to be planted in those useless lands. Breadfruit or sukun (*Artocarpus altilis* Fosberg, Moraceae) proved itself unsuitable for the harsh conditions of large parts of the *I. cylindrica* grasslands, as it only performed well at specific sites. Currently available indicators of site quality are insufficient to predict where breadfruit can be grown. The field experiments showed no statistically significant differences in tree growth linked to the method used for initial alang-alang suppression: ploughing, herbicide use or the relatively simple 'pressing' method. They proved all to be acceptable in the context of the overall system used.

Chapter 4 deals with preparatory reduction of *I. cylindrica* biomass in the study sites, the land cover, cover crop biomass and nutrient content, annual food crops, dynamics of soil fertility and farmer response to the agroforestry system tested. The spraying of herbicide and ploughing are the most efficient methods to reduce alang-alang biomass as a first step in the conversion of the alang-alang ecosystem into an agroforestry ecosystem. The pressing method may be the cheapest method to prepare acceptable tree growth, but was less attractive for inter-cropping because it led to poorer overall control due to surviving grass. Less complete *I. cylindrica* control after the first year in the second block made the farmer decide to refrain from inter-cropping with food crops, and thus to further chances of the grass to regrow. As a cover crop, able to outshade alang-alang after one year, to prevent its recovery and to improve soil fertility at the same time, *Pueraria javanica* (Leguminosae-Fabaceae) is a good option. An overall tree-LAI ≤ 1 and an overall rate of tree-shading ≤ 40 % are conditions for maximal corn yields by intercropping in a matrix of diverse trees species. To stimulate farmer's interest in the agroforestation techniques tested in the study sites some levels of incentive (e.g. subsidized provision of planting material) will be required, as agroforestation as such is unlikely to discourage the activities inside the forest areas for direct income.

Chapter 5 reports on the architecture, root distribution and biomass assessment of the four tree species grown in the trial plots. The architectural models and dynamics of the four tree species are described, as well as the procedures of the Functional Branching Analysis. Mahogany and sungkai have a crown architecture and a root distribution apt to stimulate the establishment of an agroforestry system, because they are particularly apt to live together with annual plants. Candle nut, however, is more appropriate to reduce *I. cylindrica* grass by shading with its wide, dense hemispherical crown. Timber and multipurpose tree species have different growth rates and growth rhythms of their above-ground parts. During early establishment, timber tree species have a lower above-ground biomass than multipurpose tree species. Functional Branching Analysis (FBA) software can yield estimates of above ground biomass of mahogany and sungkai with an average standard deviation of 1 ± 0.34. This software should be improved in order to accommodate biomass more precisely in the case of trees with different temperaments and particularly, with early and profuse reiteration.

Chapter 6 presents some practical conclusions with regard to the importance of the research findings for the scientific understanding of complex living systems. A synthesis is made of the research results and site quality differences within the *I. cylindrica* domain is tried to be recognized, as well as the options for inter-cropping based on tree crown shape and roots distribution. Beyond the technical questions addressed in this research, a number of other conditions is identified that have to be met before spontaneous, widespread adoption of agroforestation techniques by smallholders can be expected. While conversion of alang-alang grasslands into more productive and sustainable land uses is technically feasible, a broader approach to household level livelihood options may be needed to better understand the incentive structure needed to achieve real-world impacts of this research. In particular, the general image of the problems and possibilities in managing a complex “mixed” cultivation system according to its nature finds itself strengthened and clearer, this being in line with the results of the seven research projects at PhD level, of which the present one is the last.

SAMENVATTING

“Van *Imperata cylindrica* grasland tot productieve boslandbouw” gaat over technische keuzen voor de omvorming van door *I. cylindrica* , dat is alang-alang-gras, gedomineerde ecosystemen in een productief agroforestry ecosysteem, bruikbaar voor kleine boeren of bosboeren. Het hier beschreven onderzoeksproject behandelt een aantal voorwaarden voor zo’n omvorming. Dat zijn de volgende. 1) Er moeten bomen gevonden worden die genoegen nemen met de lage vruchtbaarheid van de groeiplaats, die voldoen aan de voorkeur van de bewoners inzake de opbrengst aan fruit, boerengeriefhout of zaaghout, en waarvan zaailingen in kwekerijen door de boeren of er vlakbij kunnen worden gekweekt. 2) Deze bomen moeten verzekerd zijn van voldoende mutualistische microbiële interacties, met ofwel in het grasland aanwezige, ofwel in de kwekerij geïnoculeerde mycorrhizenschimmels. 3) Vrij eenvoudige methoden moeten worden gevonden om het alang-alang-gras, dat t.a.v. de conversie als “onkruid” gezien wordt, op voor kleine boeren financiëel en qua arbeid haalbare wijze te onderdrukken. 4) Tenslotte dient de haalbaarheid van gemengde teelt met voedselgewassen in de vroege jaren van het systeem getoetst te worden. Bij dit laatste wordt kunstmest gebruikt waarvan de bomen worden geacht mee te profiteren, zodat ze al vroeg producten en diensten verschaffen die de investering van arbeid rechtvaardigen. Buiten bovenstaande technische vereisten werden er enige “essentiële voorwaarden” vastgesteld waaraan moet worden voldaan vooraleer een spontane en wijd verbreide aanvaarding van deze conversiemethoden kan worden verwacht. Evenwel is het huidige werkstuk op de vier technische aspecten toegesneden.

De studie werd verricht nabij het Wanariset I Onderzoeksstation, rond 38 km ten noordoosten van Balikpapan, Oost Kalimantan, Indonesië. De veldproeven lagen in een transmigratiegebied, zo’n 20 tot 27 km ten noordwesten van dit station. Proeven in de kwekerij en klaarmaken van zaailingen vonden plaats op het station zelf.

Dit werk telt zes hoofdstukken. Het eerste geeft een algemene inleiding met literatuurstudie van *I. cylindrica*, zijn identiteit en gedrag, als soort en als dominante graslandcomponent. De literatuur was ook de bron voor gegevens over het gras als indicator van arme bodems, als component van gedegradeerd of in successie vastgelopen bos, of van woeste gronden, als factor in koolstofvastlegging, en voor wat betreft de kansen om door conversie de druk op het omliggend bos te verminderen. Op het Wanariset I station had eerder onderzoek duidelijk aangetoond dat kweek van dipterocarpaceeënbomen niet kan zonder enting met mycorrhizae. De literatuur over ectomycorrhizen en arbusculair-vesiculaire mycorrhizen in agroforestry-systemen en herbebossingsmethoden werd daarom besproken. Tenslotte definiëert dit hoofdstuk de wetenschappelijke problemen, het kader en de doelstellingen van de studie.

Hoofdstuk 2 beschrijft nauwkeurig de biofysische en sociaal-economische kenmerken van de groeiplaatsen op het onderzoeksterrein. Voorafgaand onderzoek in die streek toonde dat rond de helft van het gemeenschappelijke inkomen kwam uit bezigheden in het bos, dwz. illegale kap. Daarom juist maakten de overvloed aan verlaten alang-alang-gronden en de schaarste aan boerenbedrijfjes deze groeiplaatsen tot een voorwerp van onderzoek, bij uitstek geschikt voor wat betreft de technische aspecten van omvorming ten gunste van productief landgebruik. Toch bleek de doelstelling om locale bewoners een nieuwe vorm van landbouw te verschaffen die ze een inkomen kon opleveren, vergelijkbaar met dat van een "normale" boerderij, hoog gegrepen.

Hoofdstuk 3 rapporteert de groeicijfers voor vier geselecteerde boomsoorten in alang-alang-grasland en toetst de noodzaak van enting met myccorrhizen in de kwekerij om de groei na uitplanten te stimuleren. Deze enting bleek de groei van zaailingen niet noemenswaard te bevorderen. In deze fase geënte bomen vertoonden weliswaar een statistisch significant hoger overlevingspercentage na uitplanten, maar dit betrof toch niet meer dan 6,5 %. Op de biomassagroei van de overlevenden had enting in de kwekerij geen enkel positief effect. De gegevens steunen dus geenszins de dwingende noodzaak van enting met het gebruikte inoculum. Blijkbaar was het potentiëel van het van nature in alang-alang-grasland aanwezige inoculum voldoende.

De prestaties van drie van de vier geselecteerde en in alang-alang-land geplante boomsoorten en hun vermogen om het gras ten dode te beschaduwen, namelijk de grootbladige Mahonie (*Swietenia macrophylla* King, Meliaceae), Sungkai (*Peronema canescens* Jack, Verbenaceae) en de Kaarsvetnoot of "Candle nut" (*Aleurites moluccana* (L.) Willd.,Euphorbiaceae) maken deze drie de geschiktste voor aanplant op deze woeste gronden. De Broodvrucht of Sukun (*Artocarpus altilis* Fosberg, Moraceaae) bewees ongeschikt te zijn voor de rauwe omstandigheden in grote delen van alang-alang-grasland, want deze presteerde slechts veel op speciale groeiplaatsen hier en daar in de *I. cylindrica*-velden. Er staan nog niet genoeg groeiplaatsindicatoren ter beschikking om te voorspellen waar de Broodvrucht kan worden geteeld. De proeven vertoonden evenmin statistisch significante groeiverschillen die verbonden waren met de methode van alang-alang-onderdrukking. Onderploegen, chemische onkruiddoders of het vrij eenvoudige "platwalsen" waren om het even als eerste fase van omvorming naar het beoogde systeem.

Hoofdstuk 4 gaat over deze voorbereidende vermindering van *I. cylindrica* biomassa op de proefvelden, over de bedekkingsgraad, de biomassa en het nutriëntengehalte van de gewassen, over eenjarige gewassen, de dynamiek van de bodemvruchtbaarheid en de respons van de boeren ten opzichte van de getoetste methodieken. Toediening van onkruiddoders en onderploegen zijn het doelmatigst als eerste stap in de conversie. Platwalsen van het gras is misschien wel het goedkoopst, maar ook het minst aantrekkelijk, omdat het overgebleven gras moeilijk beheersbaar was en als onkruid tussen de eenjarige gewassen optrad. Als de boer dat merkte, liet hij de eenjarige teelten in de volgende jaren achterwege, hetgeen de kansen op terugkeer van het gras weer verhoogde. Daarom is een bodembedekkend gewas, dat het gras dood kan schaduwen, de terugkeer ervan verhinderen, en tegelijk de bodemvurchtbaarheid kan verhogen een goede keuze, met name *Pueraria javanica* (Leguminosae-Fabaceae). Een gemiddelde algehele boom-LAI ≤ 1 en een gemiddelde algehele boomschaduw ≤ 40 % zijn voorwaarden voor maximale mais-opbrengsten bij menging in een matrix van verschillende boomsoorten. Om de interesse van boeren in de op deze groeiplaatsen getoetste technieken te verhogen zijn een aantal stimuleringsmaatregelen onmisbaar, zoals aanbod van plantmateriaal met subsidie, omdat agroforestatie als zodanig waarschijnlijk de bosbezigheden zoals illegale kap niet kan ontmoedigen.

Hoofdstuk 5 gaat over architectuur, worteldistributie en de schatting van biomassa van de vier boomsoorten in de proefvlakken. De architectuurmodellen en groeidynamiek van de vier boomsoorten zijn beschreven, alsmede de procedures van Functionele Vertakkings Analyse (FBA). Qua kroonarchitectuur en wortelstelsel stimuleren Mahonie en Sungkai het boslandbouwsysteem, aangezien ze daardoor bijzonder makkelijk met eenjarigen kunnen samenleven. Daarentegen is *A. moluccana* geschikter om alang-alang-gras dood te schaduwen met zijn dichte, halfbolvormige, wijde kroon. Bomen voor zaaghout en voor veelsoortig gebruik tonen verschillende groeisnelheden en –rythmes van de bovengrondse delen. Gedurende hun vestiging hebben werkhoutbomen een lagere bovengrondse biomassa dan bomen voor veelvoudig gebruik. FBA programmatuur is in staat schattingen te leveren van de bovengrondse biomassa van Mahonie en Sungkai met een standaardafwijking van 1 ± 0.34. Deze programmatuur zou verder moeten worden ontwikkeld om ook exactere biomassa-schattingen te kunnen maken bij bomen met andere temperamenten, in het bijzonder met vroege en overvloedige reïteratie.

Hoofdstuk 6 bevat enkele conclusies over het belang van bovenstaande bevindingen voor het begrip van complexe levende systemen en voor de praktijk. Een poging tot synthese van de resultaten geeft aanwijzingen om verschillen in groeiplaatskwaliteit binnen het domein van *I. cylindrica* te onderscheiden, alsook opties voor gewasmenging op basis van boomkroonarchitectuur. Buiten de door de huidige studie bestreken technische aspecten zijn nog een aantal andere voorwaarden geïdentificeerd die bepalen of al dan niet een spontane en brede aanvaarding van dit soort systemen door de boeren mag worden verwacht. Ofschoon conversie van alang-alang-gronden naar productieve agroforestry-velden technisch mogelijk is, is er waarschijnlijk een bredere benadering nodig op het niveau van de broodwinning per huishouden, als men een reële en niet slechts een virtuële invloed van dit onderzoek wenst. In het bijzonder is op grond van het huidige onderzoek het beeld van beheer van complexe, "gemengde" teeltsystemen volgens hun eigen natuur verhelderd en versterkt. Dit alles spoort in grote lijnen met de inzichten verworven uit een samenhangende serie van zeven promotie-onderzoeken in Kalimantan, afgesloten door het huidige project.

RINGKASAN

“From *Imperata cylindrica* Grasslands to Productive Agroforestry” membahas pilihan-pilihan secara teknis yang dapat digunakan oleh petani kecil dalam rangka konversi ekosistem lahan alang-alang menjadi ekosistem agroforestry yang productive. Beberapa hal penting yang diperlukan dalam proses konversi tersebut dilaporkan, yaitu: 1) beberapa jenis pohon yang sesuai dan mampu tumbuh dengan baik di lahan dengan status kesuburan tanah yang rendah, sehingga dapat memenuhi kebutuhan petani terhadap kayu dan buah, dimana bibit dapat disediakan di persemaian yang dapat dijangkau oleh petani; 2) jenis-jenis pohon tersebut membentuk asosiasi mikoriza baik dengan cendawan yang sudah ada di lahan alang-alang itu sendiri atau dengan cendawan yang diinokulasikan pada bibit di persemaian; 3) methoda sederhana untuk menanggulangi alang-alang sebagai gulma dengan biaya dan tenaga kerja yang terjangkau oleh petani kecil; 4) kelayakan tumpangsari dengan tanaman semusim pada tahun-tahun pertama untuk memperoleh hasil dan keuntungan pada fase awal dari sistem agroforestry sehingga memungkinkan investasi dalam proses konversi dimaksud. Selain persyaratan teknis diatas, telah pula diidentifikasi sejumlah kondisi penting lainnya yang harus dipenuhi sebelum adopsi secara luas dan spontan dapat diharapkan dari methoda konversi ini. Tetapi penelitian dan disertasi ini difokuskan pada empat aspek teknis diatas.

Penelitian dilaksanakan di sekitar areal Stasiun Penelitian Wanariset I, 38 km ke arah Timur Laut dari kota Balikpapan, Kalimantan Timur, Indonesia. Penelitian lapangan berlokasi di areal transmigrasi, 20 sampai 27 km ke arah Barat Laut dari Stasiun Penelitian Wanariset I, sedangkan percobaan persemaian dan persiapan bibit dilaksanakan di persemaian Stasiun Penelitian Wanariset I itu sendiri.

Disertasi ini terdiri dari enam bab. Bab pertama adalah pendahuluan secara umum yang menyajikan tinjauan pustaka tentang *I. cylindrica*, baik sebagai tumbuhan maupun sebagai komponen yang dominan pada lahan atau padang alang-alang. Berbagai perspektiv: indikator tanah yang tandus, degradasi hutan, fase blok dalam suatu proses suksesi alam, lahan terlantar, penangkapan carbon, upaya rehabilitasi untuk mempertahankan areal hutan yang tersisa, dikemukakan dalam tinjauan pustaka ini. Berdasarkan pengalaman di Stasiun Wanariset yang telah dengan jelas teridentifikasi kebutuhan inokulasi mikoriza untuk jenis-jenis Dipterocarp, literatur tentang mikoriza (ekto dan juga arbuskular) ditinjau dalam konteks system agroforestry dan tekhnologi reforestasi. Selain itu, bab ini juga mendefinisikan problem secara ilmiah dan praktis, memformulasikan studi serta tujuan penelitian.

Bab dua menguraikan risalah lokasi penelitian secara detail, baik aspek bio-fisik maupun kondisi sosial-ekonomi masyarakatnya. Baseline survey yang dilakukan di lokasi penelitian menunjukkan bahwa hampir 50% dari pendapatan masyarakat berasal dari kegiatan di dalam hutan, seperti penebangan liar. Luasnya lahan alang-alang yang ditinggalkan (lahan terlantar yang tandus) dan langkanya usahatani di desa-desa transmigrasi dimaksud, menjadikan lokasi ini sebagai objek penelitian yang baik untuk aspek teknis dalam konversi lahan alang-alang menjadi lahan yang lebih produktiv. Akan tetapi, tujuan untuk membekali masyarakat dengan suatu bentuk penggunaan lahan pertanian yang dapat memberikan pendapatan usahatani yang bersaing memerlukan proses yang panjang.

Bab tiga melaporkan pertumbuhan dari empat jenis pohon terpilih di lahan alang-alang dan pengujian terhadap kebutuhan untuk inokulasi bibit dengan cendawan mikoriza di persemaian sebagai suatu cara untuk meningkatkan pertumbuhan pohon di lapangan. Di persemaian, inokulasi dengan cendawan mikoriza (‘resting spores’ dalam ‘Mycofer’ yang terdiri dari *Glomus manihotis*, *Glomus etunicatum*, *Gigaspora rosea* dan *Acaulospora tuberculata*) tidak meningkatkan pertumbuhan bibit. Inokulasi pada fase ini meningkatkan persen tumbuh secara nyata setelah bibit dipindahkan ke lapangan. Namun demikian, rata-rata peningkatan persen tumbuh dari empat jenis pohon hanya 6,5%. Inokulasi bibit di persemaian tidak memberikan efek positiv pada fase pertumbuhan pohon berikutnya setelah melewati fase awal yang kritis. Data pertumbuhan pohon menunjukkan tidak ada kebutuhan yang memaksa untuk menggunakan inokulum tipe tersebut di persemaian. Inukulum potensial dari lahan alang-alang untuk jenis-jenis pohon yang tergantung pada mikoriza arbuskular nampaknya sudah mencukupi.

Penampilan dari empat jenis pohon terpilih yang ditumbuhkan di lahan alang-alang, dan kemampuannya untuk menekan pertumbuhan gulma tersebut, menentukan apakah jenis-jenis ini cocok untuk ditanam dilahan marginal dimaksud. Mahoni (*Swietenia macrophylla* King, Meliaceae), sungkai (*Peronema canescens* Jack., Verbenaceae) dan kemiri (*Aleurites moluccana* (L.) Willd., Euphorbiaceae) terbukti cocok untuk ditanam di lahan alang-alang, sedangkan sukun (*Artocarpus altilis* Fosberg, Moraceae) nampaknya tidak sesuai dengan kondisi sebagian besar lahan alang-alang yang tandus, karena jenis ini hanya tumbuh baik pada tempat-tempat yang khusus. Indikator qualitas lahan atau tapak yang disajikan pada tesis ini belum mencukupi untuk memprediksi dimana sukun dapat tumbuh dengan baik. Penelitian ini menunjukkan tidak ada perbedaan yang nyata secara statistik dalam pertumbuhan pohon dalam kaitannya dengan metoda pengendalian awal alang-alang yang digunakan: pengolahan tanah (pencangkulan), penggunaan herbisida atau metoda yang relative sederhana “pressing” (merebahkan alang-alang). Semua metoda ini terbukti dapat diterima dalam konteks sistem secara keseluruhan.

Bab empat membahas pengurangan biomasa *I. cylindrica* di lokasi studi, penutupan lahan, biomasa tanaman penutup tanah (cover crop) dan kandungan haranya, tanaman pangan semusim, perbaikan tingkat kesuburan tanah dan tanggapan petani terhadap metoda agroforestry yang diuji. Penyemprotan herbisida dan pencangkulan adalah metoda yang efisien untuk mengurangi biomasa alang-alang sebagai langkah awal dalam konversi ekosistem alang-alang menjadi ekosistem agroforestry. Pressing adalah metoda yang paling murah untuk mempersiapkan pertumbuhan pohon yang dapat diterima, tetapi kurang menarik untuk kegiatan tumpangsari karena metoda ini menghasilkan pengendalian alang-alang yang kurang efektif disebabkan oleh tingginya masa alang-alang yang tumbuh kembali. Kurang sempurnanya pengendalian *I. cylindrica* setelah tahun pertama di blok dua, menyebabkan petani menahan diri untuk menanam tanaman tumpangsari. Hal ini memberi peluang berikutnya pada alang-alang untuk tumbuh kembali. Sebagai tanaman penutup tanah, yang dapat meliputi alang-alang setelah satu tahun, dan dapat mencegah alang-alang tersebut tumbuh kembali serta dalam waktu yang sama dapat memperbaiki kesuburan tanah, *Pueraria javanica* (Leguminosae-Fabaceae) adalah pilihan yang tepat. Rata-rata LAI pohon ≤ 1 dan rata-rata naungan pohon ≤ 40 % adalah kondisi untuk memperoleh hasil jagung yang maksimal dalam sistem tumpangsari dengan beberapa spesies pohon. Untuk memotivasi minat petani dalam tekhnik "agroforestation" yang diuji di lokasi studi, dibutuhkan beberapa tingkat insentiv misalnya subsidi bahan tanaman, karena "agroforestation" tersebut nampaknya belum mengurangi kegiatan di dalam areal hutan untuk memperoleh pendapatan langsung.

Bab lima melaporkan architektur pohon, distribusi perakaran dan estimasi biomasa dari empat spesies pohon yang ditumbuhkan di plot percobaan. Model-model pohon secara architecture dan dinamica dari ke empat spesies pohon tersebut dideskripsikan dan juga prosedur analisa percabangan secara fungsional (Functional Branching Analysis). Mahoni dan sungkai mempunyai architektur tajuk dan distribusi perakaran yang tepat dan cocok untuk membangun system agroforestry, karena spesies ini cocok untuk hidup berdampingan dengan tanaman semusim. Kemiri lebih cocok untuk menekan pertumbuhan *I. cylindrica* melalui naungan tajuknya yang lebar, padat dan bulat. Jenis pohon kayu (timber) dan pohon serbaguna mempunyai laju dan ritme pertumbuhan diatas tanah yang berbeda. Pada awal pertumbuhan, spesies pohon kayu mempunyai biomasa diatas tanah yang lebih rendah dibandingkan dengan spesies pohon serbaguna. Perangkat lunak (software) analisa percabangan secara fungsional (Functional Branching Analysis, FBA) dapat mengestimasi bagian biomasa diatas tanah dari mahoni dan sungkai dengan rata-rata standar deviasi 1 ± 0.34. Software ini perlu disempurnakan untuk dapat mengestimasi biomasa pohon dengan lebih tepat dalam kasus pohon dengan temperamen yang berbeda, khususnya pohon yang membentuk pengulangan (percabangan) dalam fase awal yang berlimpah.

Bab enam menyajikan beberapa kesimpulan praktis yang menekankan pentingnya hasil-hasil penelitian untuk pengertian secara ilmiah dari sistem kehidupan yang kompleks. Sintesa dari hasil-hasil penelitian dibuat dan perbedaan qualitas lahan pada areal *I. cylindrica* dicoba untuk dikenali, juga pilihan-pilihan untuk tumpangsari berdasarkan bentuk-bentuk tajuk pohon dan distribusi akar. Disamping hal-hal teknis yang dipelajari dalam penelitian ini, juga diidentifikasi sejumlah kondisi lainnya yang harus dipenuhi sebelum adopsi secara luas dan spontan oleh petani kecil dapat diharapkan. Sementara konversi lahan alang-alang menjadi lahan yang lebih produktiv dan lestari layak secara teknis, pendekatan yang lebih menyeluruh pada tingkat rumah tangga dalam hal pilihan mata pencaharian nampaknya dibutuhkan untuk memperoleh pengertian yang lebih baik dalam hal struktur insentiv yang dibutuhkan untuk mencapai hasil yang nyata dari penelitian ini. Secara khusus, kesan umum dari persoalan dan kesempatan dalam mengelola sistem budidaya campuran yang kompleks secara alami ditemukan lebih kuat dan lebih jelas. Hal ini sejalan dengan hasil-hasil dari tujuh proyek penelitian tingkat PhD, dimana hasil yang disajikan dalam buku ini adalah yang terakhir.

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APPENDIX 1

THE AVERAGE SURVIVAL, DIAMETER AND HEIGHT GROWTH OF THE FOUR TREE SPECIES (MAHOGANY, *Swietenia macrophylla*; SUNGKAI, *Peronema canescens*; CANDLE NUT, *Aleurites moluccana* AND SUKUN, *Artocarpus altilis*) ACCORDING TO MYCORRHIZAL TREATMENT, 3, 6, 12, 18 AND 24 MONTHS AFTER PLANTING

Variables	Time (months after planting)				
	3 months	**6 months**	**12 months**	**18 months**	**24 months**
Survival (%):					
• Mahogany					
- Inoculated	97.5	97.5	97.5	97.5	97.5
- Not inoculated	94.0	95.0	92.7	92.7	92.2
• Sungkai					
- Inoculated	88.5	88.5	86.1	85.1	84.4
- Not inoculated	84.8	84.8	82.5	82.1	81.6
• Candle nut					
- Inoculated	96.9	92.5	88.2	87.5	87.5
- Not inoculated	90.1	90.1	86.2	86.2	85.4
• Sukun					
• Inoculated	95.1	91.0	83.4	78.0	76.4
• Not inoculated	90.2	90.2	76.5	70.4	60.8
Diameter growth (cm):					
• Mahogany					
- Inoculated	-	0.642	1.671	3.572	5.631
- Not inoculated	-	0.620	1.517	3.502	5.260
• Sungkai					
- Inoculated	-	0.608	1.849	3.89	5.61
- Not inoculated	-	0.593	1.830	4.53	6.56
• Candle nut					
- Inoculated	-	0.669	1.85	4.08	6.27
- Not inoculated	-	0.585	1.81	4.34	6.45
• Sukun					
- Inoculated	-	0.384	0.770	1.81	2.79
- Not inoculated	-	0.534	0.827	2.46	4.02

Variables	Time (months after planting)				
	3 months	**6 months**	**12 months**	**18 months**	**24 months**
Height growth (cm):					
• Mahogany					
- Inoculated	-	40.3	93.6	184.0	293.5
- Not inoculated	-	31.4	91.3	180.9	290.7
• Sungkai					
- Inoculated	-	23.93	83.0	178.8	246.8
- Not inoculated	-	24.30	89.2	197.7	284.1
• Candle nut					
- Inoculated	-	39.5	114.7	213	311
- Not inoculated	-	32.3	104.5	214	323
• Sukun					
- Inoculated	-	19.5	34.0	58.4	106
- Not inoculated	-	15.6	31.0	73.7	139

LIST OF ABBREVIATIONS

Al = aluminium
ANOVA = analysis of Variance
Asl = above sea level
Ca = calcium
ºC = degree Celsius
CEC = cation exchange capacity
CL = Clay Loam
$C_{organic}$ = Carbon organic
C_{org} = see $C_{organic}$
Cu = copper
cm = centi meter
cmol$_e$ kg^{-1} = centi moll equivalent per kilo gram
DMRT = Duncan's Multiple Range Test
d = stem diameter
d_{ar} = diameter above root
d_{bh} = diameter at breast height
dm = decimeter
dmaxfin = diameter of a link when leaf density maximum
dmin = diameter of a link when branching stopped
d_r = root diameter
dzerofin = diameter of a link when leaf density zero
E = East
ECM = Ecto mycorrhizae
FBA = Functional Branching Analysis
Genstat = General Statistics
GO = Government Organisation
g = gram
g = gini coefficient
HH = Household
H_{root} = horizontal root
h = height
ha = hectare
INHUTANI = Forest State Enterprise
I_l = light intensity
intercept = intercept of regression equation between diameter and length of links
K = potassium
Kg = kilo gram
LAI = Leaf Area Index
M = Million

Mg = Magnesium
Mg ha^{-1} = Million gram per hectare
m = meter
maxfindens = number of leaves per centimeter of link
mg = milligram

mm = millimeter
MOF = Ministry of Forestry
N = nitrogen
NGO = Non Government Organisation
nm = nano meter
n_sub = average number of branches
P = phosphorus
PAR = photosynthetically active radiation
p = transfer coefficient of cross sectional area before and after branching
par = paragraph
PELITA = Five years plan
pop = population
PRA = Participatory Rural Appraisal
PT ITCI = International Timber Corporation Indonesia
q = allocation coefficient among branches
range_L = relative range for links length
Rp = Rupiah (Indonesian currency)
S = South
SC = Sandy Clay
SCL = Sandy Clay Loam
SL = Sandy Loam
SLA (m^2g^{-1}) = Specific Leaf Area (meter square per gram)
S_c = Crown surface
US$ = United State Dollar
UP-UPSA = demonstration plot for natural resources
UP-UPM = demonstration plot for permanent agriculture
µmoll s^{-1} m^{-1} = micron moll per second per meter square
VA mycorrhizae = Vesicular – Arbuscular mycorrhizae
V_{root} = Vertical root
v = wood volume
vol. % = volume in percent
W_c = Crown width
Zn = Zinc

CURRICULUM VITAE

Murniati was born on August 30, 1959 in Bukit Tinggi (West Sumatera Province, Indonesia). She completed high school at the SMA PPSP IKIP Padang in 1977. She studied in the Bogor Agricultural Institute (IPB) from 1978 to 1982 at the Faculty of Agriculture, under the agronomy department. She started working as a junior researcher at the Forest Research and Development Centre, Bogor in 1984. She took a postgraduate course in the Forestry Science of the postgraduate programme of IPB from 1992 to 1995. She has attended several training courses and workshops in the field of Agroforestry and Community Forestry in her own country and abroad.

She was admitted to a PhD sandwich program for this PhD thesis at the Wageningen University and Research (WUR), the Netherlands in September 1998 in the framework of the international co-operation between the Ministry of Forestry of the Republic of Indonesia and Tropenbos International. On the first day of 1983 she married Muhamad Halef and they were blessed with a daughter Selfia Kusumawati and two sons Hafi Febrianto and Vicky Firdaus.

Cover photo: *Imperata cylindrica* Grassland (Riskan Effendi), insert with a Productive Agroforestry System (Murniati)
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