USING NATIVE TIMBER TREES FOR RECOVERING DEGRADED LANDSCAPES IN THE PHILIPPINES:

Social, biophysical and economic assessment of agroforestry systems practised by smallholder farmers

Author:

Fernando Santos Martín

SUMMARY

This study was designed to gain a better understanding of the current land used decisions that lead to rapid conversion of tropical forest margins and the slow process of rehabilitation and development of sustainable land use practices on deforested areas in the past. The overall hypothesis is that “Using native timber for recovering degraded landscapes can result in land use that is both sustainable and productive”. Three main requisites need to be test to answer this general hypothesis. Are timber based agroforestry systems with native timber tree species (i) Socially acceptable; (ii) Biophysically feasible and; (iii) Economically profitable?

Thesis introduction present the big picture, describing what are the driving forces of deforestation and tree planting in the Philippines and other tropical countries especially in Southeast Asia. General and specific hypothesis and objectives are presented in Chapter 2 together with the overall framework and flow-chart of the thesis that guided the work. Chapter 3 presents the results from the socio-economic survey conducted among smallholder in four different upland communities revealing which are the major factors influencing farmers’ capacity and intention to plant timber trees. Chapter 4 presents data on where farmers are actually planting native timber tree species across the agricultural landscape and evaluates these results in relation to tree growth performance. Chapter 5 develop a tree database for the most promising native tree species and estimates above-ground tree biomass utilizing destructive and non-destructive methods which will allow further analysis using model simulations tools. Chapters 6 and 7 evaluate timber based agroforestry systems with native tree species from the biophysical and economic point of view. Chapter 6 presents biophysical results from model simulations and evaluates the feasibility and sustainability of a wide array of possible management options where trade-offs between tree growth and crop yield is presented in a simple and innovative format. Chapter 7 converts biophysical model simulations results into economic values (using external price data) and evaluates the profitability and risk resilience of each system under different macroeconomic conditions. Overall thesis conclusions are discuss in Chapter 8, where the consolidation of each individual chapter results lead to synthesized what are the policy and economic determinants needed to facilitate the forest transition that is likely to take place in the Philippines.

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LIST OF ACRONYMS / ABBREVIATIONS

AECI:	Agencia Española de Cooperación Internacional
BAS:	Bureau of Agricultural Statistics
CD:	Coefficient of Determination
CDM:	Clean Development Mechanism
CRM:	Coefficient of Residual Mass
DBH:	Diameter Breast Height
DENR:	Department of Environmental and Natural Resources
DR:	Discount Rate
EAI:	Equivalent Area Index
EF:	Modeling Efficiency
EU:	European Union
FAO:	Food and Agricultural Organization
FBA:	Functional Branch Análisis
FMB:	Forest Management Bureau
GDP:	Gross Domestic Product
GIS:	Geographic Information System
GPS:	Global Positioning System
GRF:	Growth Retardation Factor
GTZ:	German Agency for Technical Cooperation
HH:	Household
IC:	Intercropping
ICRAF:	International Centre for Research in Agroforestry
INRA:	Institut National de la Recherche Agronomique
ITTO:	International Tropical Timber Organization
IUCN:	International Union for the Conservation of Nature and Natural Resources
LAI:	Leave Area Index
LGU:	Local Government Unit
LSU:	Leyte State University
MC:	Monocropping
ME:	Maximum Error
NGO:	Non-Government Organization
NPK:	Nitrogen, Phosphorus and Potassium
NPV:	Net Present Value
NSCB:	National Statistical Coordination Board
NSO:	National Statistic Office
PAM:	Policy Analysis Matrix
PCARRD:	Philippine Council for Agricultural Research and Development
PhP:	Philippine Peso
PRA:	Participatory Rural Appraisal
RMSE:	Root Mean Square
SAB:	Flash and Burn
SAFODS:	Smallholder Agroforestry Options on Degraded Soils
SEA:	South East Asia
SEARCA:	Southeast Asian Regional Centre for Research in Agriculture
SLA:	Specific Leaf Area
UCO:	Universidad de Córdoba
UPLB:	University of the Philippines Los Baños
USAID:	United States Agency for International Development
USDA:	United States Department of Agriculture
WaNuLCAS:	Water, Nutrient and Light Capture in Agroforestry Systems

1. WHAT ARE THE DRIVING FORCES OF DEFORESTATION AND TREE PLANTING IN THE PHILIPPINES?

Factors and actors involve in two distinct trajectories

1. The big picture

The world is full of problems: poverty and lack of food security, environmental degradation, climate change, unequal access to resources and to sustainable livelihood options, to name just a few. These global problems tend to be connected and one cannot expect to solve problems caused by one single issue without considering the others. Much of the international debate on natural resource management in the humid tropics revolves around forest, deforestation or forest conversion. But, does it really matter at a global scale if tropical forests disappear at the current rate? The answer is a clear “yes” from the perspective of global biodiversity loss, and a partial “yes” from the perspective of global climate change, where the way this will affect real-life decisions of the rest of the world may have been exaggerated (van Noordwijk *et al.*, 2001). However, much of the concern over this issue has so far been raised by environmentalist groups from the developed part of the world. Some pressure groups in tropical countries follow their line of argument, but a stronger local context and articulation is needed before adequate responses at the local level can emerge.

Additionally, the world’s population is expected to continue increasing, with much of this population growth occurring in developing countries (Barbier, 1997). An inevitable consequence of this will be demand for new crop-land for commercial and subsistence agriculture (Photo 1.1). How much additional forest needs to be converted to agriculture will depend to some extent on how well the productivity of existing arable land is maintained or even enhanced. A number of the “forest functions” that are considered to be at risk in the “deforestation” debate can probably also be maintained after forest conversion, especially if mosaics such as the agroforest can replace the forest (van Noordwijk *et al.*, 2001).

Photo 1.1. Typical mosaics of agroforest replacing natural forest on the Philippine upland

To explain the overall land use change that is driven by the deforestation process, Mather (1992) introduced the theory of Forest Transition. Very generally it describes a sequence where forest covers first declines, and reaches a minimum before it slowly increases and eventually stabilizes.

Although this concept is related with the 'Environmental Kuznetz' Curve (Kuznetz, 1955) which predicts a bell-shaped relationship between deforestation and income, they are not identical, as the Forest Transition refers to quantitative data on forest cover and the Kuznetz curve debate to environmental service functions.

Angelsen (2007) described the gradual process of change as a continuum of four different stages (Figure 1.1). The first stage, of relatively *undisturbed forest*, is characterized by passive protection: the forest area has poor infrastructure and market access, and is therefore inaccessible for commercial exploitation. A set of *triggers* (force 1) starts the deforestation process, which accelerates through a set of *reinforcing loops* (force 2) leading into the second state, the *forest frontier*. High level of deforestation lead to forest scarcity, which together with other socio-economic and political forces initiate and/or strengthen a set of *stabilizing loops* (force 3), leading into the third stage of *forest/agricultural mosaics*. These stabilizing loops will eventually dominate; taking us into the fourth stage of reforestation termed the forest/plantation/agricultural mosaics.

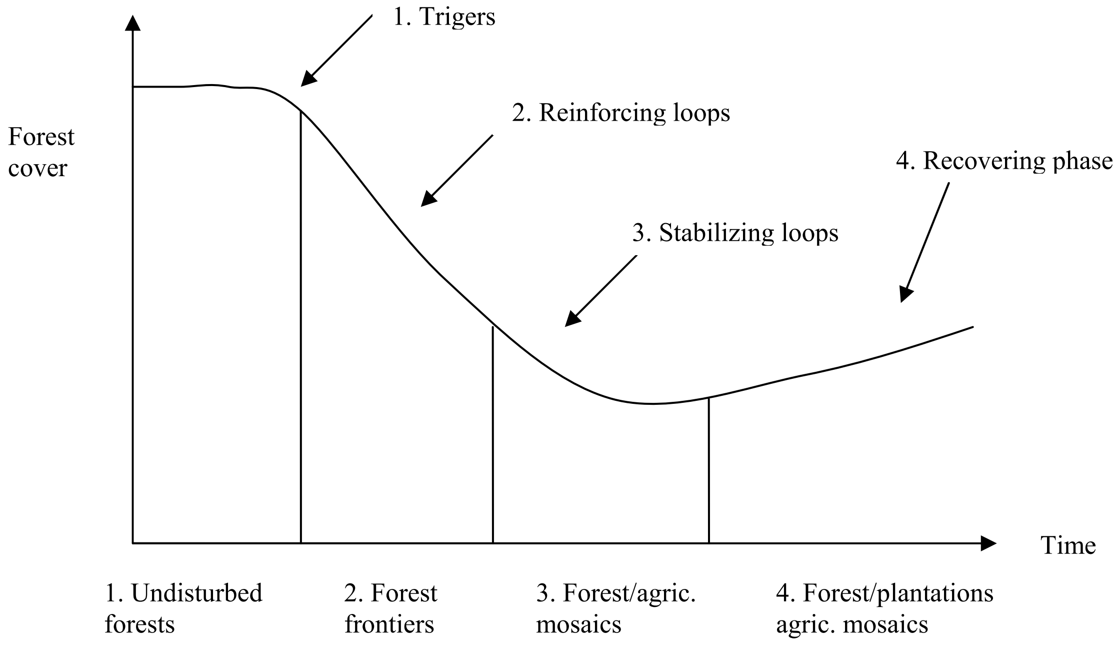


Figure 1.1. Description of forest transition theory (Source: Angelsen, 2007)

The forest transition theory adequately describes the pattern that has occurred in Europe and North America over the past two centuries (Rudel *et al.*, 2005) and makes basically two claims. First, where there is a lot of forest there will be a lot of deforestation; and second, in already deforested areas forest cover will be partly restored (Angelsen, 2007). Although this might sound trivial, it makes one pessimistic prediction: things usually have to get worse before they can get better. For example in regions with high forest cover (e.g. outer islands of Indonesia, the Congo basin, and the Amazon) will still lose a large proportion of their forest before an emerging reforestation process will (eventually) take place (Photo 1.2). This recovering process can be observed nowadays in a number of Asian countries (e.g. China, India, Vietnam) where full transition may occur over much shorter periods, decades rather than centuries (Mather, 2006).

Photo 1.2. Initial stage of landscape recovering process on a previous degraded grassland area in the Visayas, Central Philippines.

2. Land-cover change in Southeast Asia

The tropical forest of Southeast Asia contain the world's most diverse assemblage of vascular plants as well a its most economically valuable hardwoods (Rudel, 2005). Because these forests stretch across an extensive archipelago from the Salomon Islands in the Pacific to the upland regions of continental Southeast Asia, they are more fragmented than other large blocks of rain forest, in the Amazon and Central Africa. One of the distinguishing features of the forest formations in this region is the dominance of trees belonging to the *Dipterocarpaceae* family. Because of their high proportion of value timber trees, Dipterocarp forest have been rapidly logged and in many region of Southeast Asia primary forest have already disappeared or are seriously threatened (Schutel, 1996).

Two distinct trajectories of land-cover change, one for marginal upland and other for arable lowlands have evolved thorough time. In the lowlands, the extractions of logs from primary forest and the conversion of these lands to rice plantations shows no signs of slowing down (Casson, 2000). The major civilizations of the South East Asian nations developed in the lowland floodplains of the major river systems based on the practice of wetland rice cultivation (Photo 1.3). Although of great economic importance, the lowlands comprise only a small percentage of land cover, while upland represent 60-90% of the total land area in the Region (Garrity *et al*., 1997). The continued growth in internal and in some cases external markets for tropical hardwoods, coupled with the continued weakness of the state, makes it hard to conceive of how old growth natural forest might continue to survive in lowlands of Southeast Asia (Jepson *et al*., 2001).

Simultaneously, the rugged topography of upland settings plus the limited agricultural productivity of tree depleted forest land provides a hopeful note for a spontaneous agroforestation phase that may be emerging in some regions of Southeast Asia. Smallholders have transformed large areas of marginal uplands into productive agroforestry farms, increasing employment and incomes in these marginal upland rural areas (Foresta and Michon, 1993). In Sumatra, about 4 million hectares have been converted by local people into various kinds of agroforests without any external support (Potter, 1997). Indonesian farmers produce in these agroforests about 70% of the total amount of rubber exported from the country, at least 80% of the dammar resin, 80-90% of various fruits, and important quantities of main export tree crops such as cinnamon, clove, nutmeg, coffee and candle nut (Foresta and Michon, 1997). In Thailand and Malaysia, smallholders account for 95% and 72% of the total natural rubber production respectively (Bagnall-Oakeley *et al*., 1997). The Philippines uplands are also undergoing rapid transformation (Bertomeu, 2004). A study on land use change during a 40-year period (1949-1988) in the municipality of Claveria, Mindanao, showed a rapid decrease of grasslands and an expansion of perennial crops from 4% to 30% of the land surface (Garrity and Mercado, 1995). Similar transformations are also occurring in other parts of the country (Pascicolan *et al*., 1997).

Photo 1.3. Intense agricultural activity in the lowland flood-plain rice fields are a common characteristic in all Southeast Asian countries.

Agroforestation in the uplands and deforestation in lowlands corresponds roughly to the expectation of forest transition theory (Mather and Needlle, 1998), and points implicitly to the importance of trying to manage this two contrasting patterns of landscape change in ways that favour biodiversity conservation and avoid land degradation (Rudel, 2005).

3. Deforestation forces in the Philippines

The Philippines is nowadays one of the most deforested countries of the tropical world (Withmore 1984, Kummer 1992, Schulte 1996). A confluence of historical, economic, political, social, and environmental factors in the Philippines, have resulted in severe pressures on the forest resources of the country (PCARRD, 1992).

Substantial deforestation started to occur during the Spanish colonial period (1569-1898). Shifting cultivation or kaingin (Tagalog term), forbidden by a Royal Decree of June 8, 1874, and the expansion of commercial crops such as abaca (a banana relative grown for fibre), tobacco and sugar cane were probably the primary causes of forest removal at that time (Lopez-Gonzaga, 1987; McLennan, 1980; Lopez, 1996). According to Wernstedt and Spencer (1967), as cited by Kummer (1992), forest cover declined from a 90% of the total land area at the beginning of the colonization to approximately 70% by the turn of the 20'Th century (Figure 1.2). But the most dramatic changes occurred after the World War II, when extensive exploitation of the dipterocarp forests began and agriculture, driven by an increasing and impoverished rural population, expanded into forested lands. Between 1950 and 1980, forest cover declined from about 50% of the country's land area to less than 27% (Kummer, 1992). By the end of the 1990s, the Philippine government estimated forest cover to be 5.4 million hectares or a mere 22.2 % of the country's total land area, with only 800,000 ha of primary forests remaining (NSO, 1999). In other countries in the region, deforestation has also been extensive and forests resources continue to dwindle rapidly.

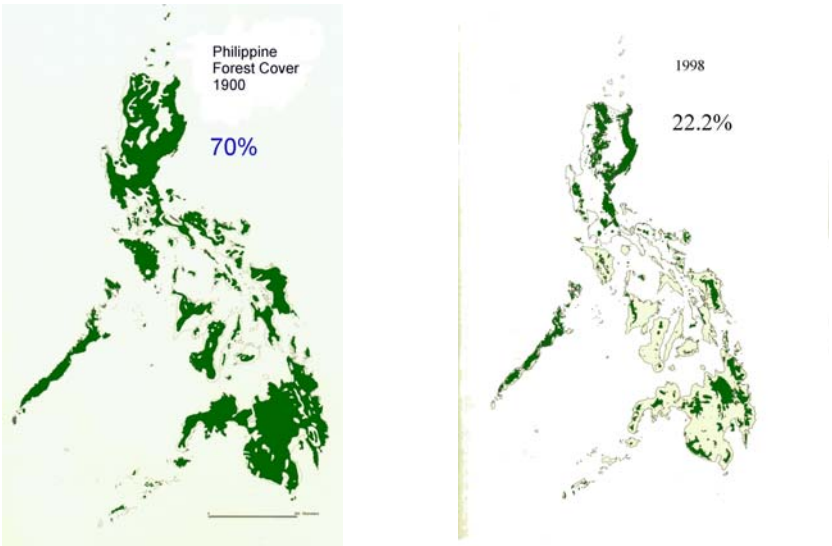
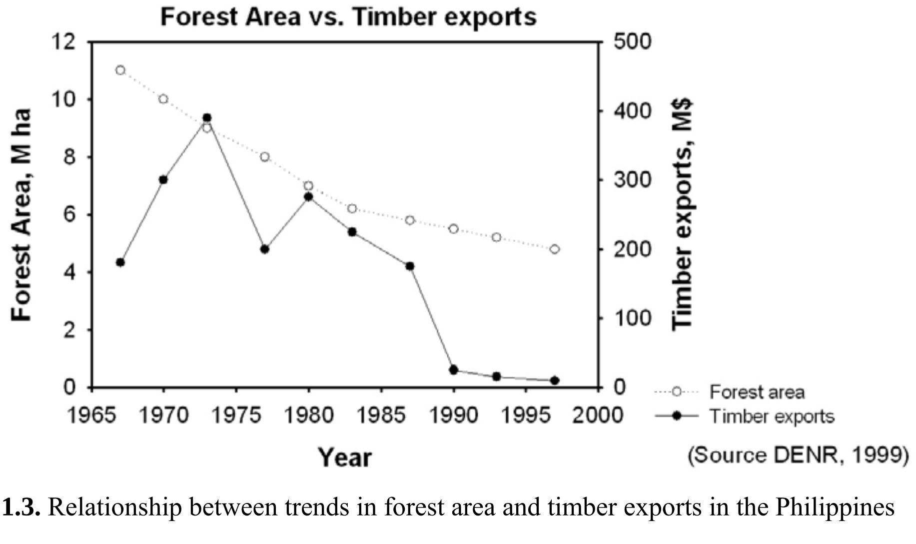


Figure 1.2. Philippine forests cover declining during the 20´th century (source: NSO, 1999)

Forestry has been one of the most important sectors in the developing economies of most Southeast Asian countries (Peluso *et al.*, 1995). During the 1960s and early 1970s, the Philippines and Thailand were the leading exporting countries of tropical timber (PCARRD, 1994), before their forests were depleted and their role taken over by Indonesia. Dipterocarp forests were the main sources of timber and other raw materials for the domestic market, employment and foreign exchange. In the Philippines deforestation was one of the engines of economic growth form the 1960's onwards, but came to a natural end in the Philippines in the 1990's as there was little accessible forest left (Figure 1.3). In 1970 in the Philippines, the forestry sector was one of the major income earners, contributing 12.5% to the gross domestic product (GDP). Forestry activities began to decline in the 1980's due to overexploitation and decreasing timber resources in 1990´s as a result the forestry sector's share of the GDP was only 1.3% (ADB, 1994).



(Source DENR, 1999)

Figure 1.3. Relationship between trends in forest area and timber exports in the Philippines

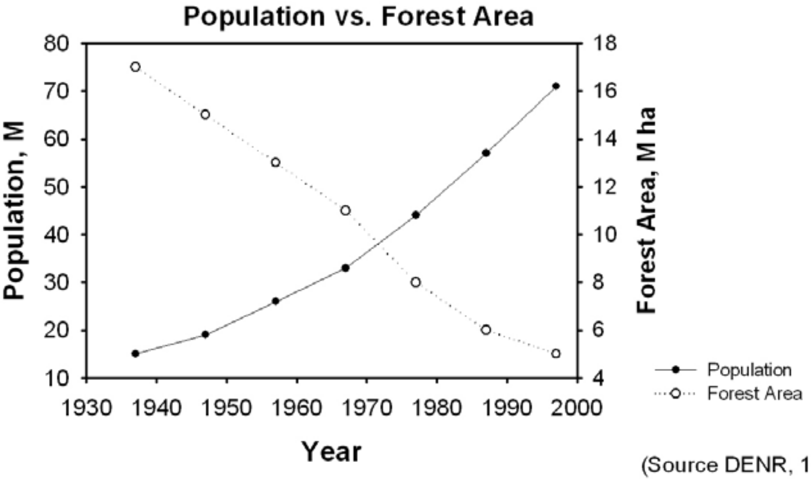
Because much of the forest conversion is based on activities that are profitable for those involved, both large logging operators and smallholder; there is thus a strong lobby to keep things as they are until there will be hardly any forest left (van Noordwijk *et al.*, 2001). Whether perceived correctly or not, the poor are seen as causing environmental degradation, particularly in the forest areas of many developing countries (Myers, 1991). Poor rural households are often found in marginal agricultural areas where land productivity, and therefore household income, is stagnant or declining. Consequently, a rational strategy for poor rural households with limited access to capital and alternative economic opportunities may be extract short-term rents through resource conversion and degradation (Barbier, 1997). The basic economic behaviour underlying the decision by farming households to abandon existing land for frontier forest land conversion has been analysed in a number of studies (Southgate 1990, Larson 1991, Barbier 1997). A farmer could invest to make the existing farming system more "sustainable" in the long term but would incur not only the direct cost of land improvement investment but also sacrifice some immediate income. In a land-abundant frontier with relatively low cost of access and relocation, the sacrifice in income includes the potential returns that could be earned form migrating to and converting new areas of forested land. Effectively, the farming household bases its decision to abandon existing land and migrate to (or further into) the frontier by assessing the perceived comparative returns from the existing and frontier land opportunities (Babier, 1997).

Historically deforestation, thus, occurred as a two-step process: primary forests were first transformed by loggers into secondary forests followed by the removal of the residual forests by the practice of agriculture (Kummer, 1992). However, deforestation is a more complex issue than simply blaming loggers and shifting cultivators. Poverty, population growth, employment, political distortion, market imperfections, environmental degradation and migration to forest frontiers are some of the ultimate driving forces of deforestation (Photo 1.4).

Photo 1.4. High population density is a common pattern on poor rural households

Poverty in the Philippines steadily increased in the past few decades until it reached 50% and 60% in urban and rural areas respectively in 1988 (World Bank, 1988). The Philippine recession of the 1980s, coupled with government incentives for capital-intensive industries and disincentives for commercial agriculture, reinforced this trend. As a consequence rural poor and displaced workers from the impoverished cities migrated to the upland frontier in search of better livelihood opportunities (Amacher *et al.*, 1998). Although urban migrants still comprise the majority of internal migration in the Philippines, the rate of growth of urban migration has decreased due to growing unemployment in industry and urban services and a general decline in the economy. In contrast, migration towards frontier forest sites, which can be opened up for cultivation, has tripled in size since the 1960s. As a results, DENR (1990) estimated that the uplands were home of more than 20 million people, of which more than 12 millions are farming in forest lands. It is estimated that at its current growth rate of over 3% per year, the upland population will double its current size by 2020 (Cruz *et al.*, 1992).

It is widely recognized that poverty and population growth contribute to environmental degradation, yet the linkages are insufficiently analyzed and documented (UNFPA, 1991). As some studies (Cruz *et al.*, 1992) point out, poverty-related factors are also population variables, and over time, both place unsustainable burdens on the environment. Traditional systems of resource use, which have been found to be sustainable at low population densities, are differentiated from the growing number of poor migrants who cultivate forest lands in order to meet short-term livelihood needs (FAO, 1989). Poverty and population growth can create a cycle of its own. Indeed the improper management of public resources, such as forest, can accentuate the negative effects of increasing population pressure (Figure 1.4). Those who share common resources may have the incentive to overexploit the resource since the benefits to the individual of restraint are marginal (Cruz *et al*., 1992). For this reason, the open access nature of forest lends itself to further degradation.



(Source DENR, 1999)

Figure 1.4. Relationship between population growth and forest area in the Philippines

In many developing countries, the problem of deforestation is also clearly linked to the process of frontier agricultural expansion and development. According to Babier (1997) many factors have been identified as having an influence on the expansion of agricultural activities such as: (i) road building that opens previously inaccessible frontier lands; (ii) land tenure or property rights (iii) policy failures and other economic distortion. Road building and insecure property rights in frontier forest areas make forest lands artificially cheap and readily available to farmers. The result of these factors is that frontier land becomes both accessible and under priced, which encourages further extensive conversion of this forest land to agriculture (Photo 1.5). Policy distortions may have a major impact on the comparative returns between poorer and wealthier households. The wealthier rural households dominate the markets for better quality arable land, whereas the poorer and landless households either trade in productive land or migrate to marginal lands. Tax and credit policies also generally reinforce the dominance of wealthier households in credit markets (World Bank, 1992). Because poorer households on the forest frontier do not benefit from such polices, their ability to compete in formal markets is further diminished. This reinforces the effect of forcing the poorer households to drift further in the forest frontier (Babier, 1997).

Photo 1.5. Isolate household living on already complete deforested area

4. Agroforestation in the Philippine’s upland

Smallholders have begun to recover degraded grassland in many parts of the Philippines, through the integration of timber trees on their farming systems (Bertomeu, 2004). During the 1970s and 1980s, population growth and continuing commercial opportunities persuaded smallholders to reduce the length of fallow periods and prevented secondary forest form remerging in fallow fields. This trend start to shift during the early 1990s, when smallholders began reclaiming *Imperata cylindrica* grasslands[1] for agroforestry by using herbicides to suppress weed growth until the tree canopy closed after several years growth and shaded out the grass (Ruf, 2001).

In the lowlands, smallholders intensified agriculture on prime agricultural lands and, in so doing, reduced shifting cultivation in adjacent upland locations (Rudel, 2005). Smallholders in the coastal lowlands installed irrigation systems in the early 1990s, began to grow additional crops of rice on their irrigated lands, and hired more labour form off the farm to cultivate the crops. The newly hired labours had practices shifting cultivation in the nearby uplands. With more paid labour now available in the lowlands, the farm workers reduced the amount of forest that they cleared each year in the uplands (Shively and Martinez, 2001). With the shift in the forces driving deforestation the Philippines after 1990, analysts begun to reassess the role that smallholders play in forest cover change. For example Fox (2001) defined smallholder farmers as: “Shifting cultivators, rather than being the hobgoblin of tropical conservation, may be ecologically appropriate, culturally suitable, an under certain circumstances the best means available for preserving biodiversity”.

Since farmers have proved to be successful tree planters, smallholder forestry has been proposed as a viable alternative to costly government-driven reforestation programs (Pascicolan *et al.*, 1997). Tree planting began to be promoted as and exceptionally profitable farm enterprise as a result of extensive deforestation and increasing timber demands (Reyes, 1994). In the early 80s, when the price of timber was high farmers were promised[2] huge returns from tree farming. Farmers seized this economic opportunity by planting fast-growing timber trees, such as *Gmelina arborea*, *Paraserianthes falcataria*, *Acacia mangium* as a cash crop. However, widespread planting of few

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1. This degraded grassland ecosystem has evolved from deforestation and intensive cultivation and is maintained in a fire climax, with soil compaction due to grazing. In the early 1990’s *Imperata* grasslands occupied around 35 million ha or 4% of the land area in tropical Asia and in the Philippines as much as 17% of the country land area (Garrity *et al.*, 1997).

2. The popular Filipino saying “Kahoy karon, bulawan ugma” (trees today, gold tomorrow) reflects the over-expectations put on tree farming.

fast-growing timber species led to oversupply and subsequently a sharp decline in the price of farm-grown timber (Garrity and Mercado, 1995).

During the past 30 years, the establishment of private industrial forest plantations and reforestation with the involvement of the rural people has been the main goals of the forestry programs of the Philippine Government. Large-scale planting of timber trees is seen as an approach to rehabilitate degraded public forest lands, provide jobs and income to rural families and produce raw materials for the wood industry (DENR, 1999). Yet, a majority of projects have failed to deliver the results foreseen. Instead, in response to favourable market conditions, smallholder farmers are producing substantial amounts of timber on private land outside the government initiative.

Ironically, outside the government reforestation areas, successful spontaneous tree planting by smallholder farmers has been practiced for many years in the Philippines without any financial assistance (Bertomeu, 2004). Indigenous people have long been managing several types of multi-storey agroforestry systems, such as the *muyong*[3] in northern Luzon or the mixed gardens found in different parts of the country (Zita *et al*., 1996; Gomez *et al*., 1998). But in the past century, in the Philippines as in many tropical countries, planted trees have become important components of farming systems. As forest disappear and land frontiers close due to population growth, farmers increase the organization and flexible repertoire of tree management strategies in order to meet their demands for various tree products (e.g., food, fuel wood, construction materials) (Raintree, 1991; Arnold and Dewees, 1997).

The failure of government-sponsored tree planting interventions is largely the result of the inadequate understanding of the goals and the socio-economic organization under which small-farm families operate (Bertomeu, 2004). Thus, tree farming, as other agroforestry technologies (e.g., contour hedgerow intercropping), has been promoted in standard extension packages (Garrity, 1996), without recognizing that many tree species with different attributes and management strategies exist, and without considering the high degree of variability between and even within households for specific tree products and services. In a typical reforestation project, few timber species and a fixed set of management practices are promoted with the sole objective of maximizing timber yields. Consequently, too many project interventions have encouraged tree growing where trees are not an appropriate component of the farm household economy, or have attempted to induce growing of inappropriate trees, or have encouraged tree management strategies not suited to farmers' goals, objectives and conditions (Raintree, 1991; Arnold and Dewees, 1997).

5. Why native trees species?

As starting point in any tree planting programme, alternative native species that might be used to provide similar benefits to the well-known exotic should first be considered (Huges, 1994). Introductions should only be contemplated if no native species are suitable for the purpose for which the introduction is being made (IUCN, 1987). In the majority of situations this simple recommendation is consistently ignored; only rarely is a through assessment of native alternative undertaken. If introduction of new species or provenances is contemplated, careful procedures need to be followed to assess risks and benefits. IUCN (1987) provided draft guidelines for choosing appropriate tree species (Table 1.1).

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[3] A local term for a private forest managed by families with an area ranging from 0.5 to 3.0 ha and composed of second growth forest and associated commercial trees (Zita *et al*., 1996).

Table 1.1. Guidelines for species introductions (adapted from IUCN, 1987)

GUIDELINES FOR SPECIES INTRODUCTIONS

1. Introductions should only be considered if clear and well-defined benefits to man or natural communities can be foreseen and demonstrated
2. Introductions should only be considered if no native species are suitable for the purpose of which the introduction is being made.
3. Introductions should not be made into pristine natural or semi-natural habitats, reserves of any kind or their buffer zones and, in most cases, oceanic islands
4. Introductions should not be made until risks of weediness or invasion of surrounding areas have been assessed as far as possible, taking into account essential data on:
    - Auto ecology of the species
    - Conditions in the area of introduction
    - Information on weediness form other areas and for closely relate species
    - Likelihood of interspecific hybridization with closely related native or other introduce species
5. Introductions should be made initially in small, closely monitored field trials.

In industrial plantation forestry, cogent argument in terms of yield gains, economics, marginal returns and uniformity of products can be made to support widespread use of a small number of exotic species that have generally outperformed native alternatives in term of survival, yield and product quality (Huges, 1994). These species have dominated industrial plantations to the exclusion of the majority of native species. Indeed, Evans (1992) suggested that 85% of industrial plantations in the tropics are established with species from three genera: *Eucalyptus, Pinus* and *Tectona*. It has been argued that many valuable species have been excluded from consideration and the growth potential of most tropical species remains unknown with only limited investments in the development of native species for plantation use. The information gap in itself favours continued use of well-known exotic although new species with potential for plantation establishment continue to be discovered (Nichols 1994, Butterfield and Fisher, 1994).

For non-industrial tree planting, the arguments in favour of choosing form only a handful of globally promoted exotic species appear to less compelling (Huges, 1994). In small scale agroforestry planting, in addition to simple evaluation of species in terms of yield (the main criterion usually employed in species elimination trials), there are wider considerations of stability, security and risk reduction, sustainability, micro-site matching product quality and timing of production in relation to seasons, compatibility with crops and livestock, market participation, and self-sufficiency and autonomy. These considerations demand use of highly diverse material that matches the diversity of products that have been traditionally harvested form natural forest. In general, the more diverse the forest in terms of species, the more secures the services and the wider range of available products (Sagent, 1992). Such planting must incorporate a wide diversity of species in any one area (Sinclair *et al.*, 1994). The "multipurpose" tree concept in itself has mitigated against use and conservation of a wider range of species (Barnes, 1990) as a way of obtaining multiple products and reducing risk. There has also been some discussion about risk reduction through careful maintenance of a broad genetic base within multipurpose species, a much simpler and more effective way to reduce risk is simply by use a wider range of species. For example, the arrival of the defoliator *Heteropsylla cubana (*Crawford) in Asia was devastating not because of the narrow genetic base in *Leucaena leucocephala (*Lam.), but because certain communities had excluded all other species (Simons, 1992).

The prevalent idea of the 1970-80´s that few "multipurpose" species could adequately meet the complex needs of resource poor farmers is now being overtaken by new strategies for choice of species that concentrate on a wider range of local trees (Leaky and Simons, 1998). Local species have the advantage of being non-invasive, well adapted to the environment, accepted by local people, of having a wide range of existing uses supported by existing local knowledge and may be important in the local culture. Additional benefits of genetic conservation through use in agroforestry (Cooper *et al*., 1992; Pimental *et al*., 1992; Gajaseni and Jordan 1992) also argue for wider use of native species. Conversely, wide use of exotic trees in farm and agroforestry may greatly hasten the demise of native trees that are used in traditional agroforestry systems (Hellin and Huges, 1993). Indeed promotion of exotic agroforestry trees over indigenous alternatives strongly parallels of the loss of traditional crop varieties (Altieri and Merrick 198; Cooper *et al*., 1992). However, greater attention to propagation methods for native species can often yield rapid results (Tietema *et al*., 1992).

Rarely is time taken to investigate the potential of lesser-known local species for which seed may not be readily available and for which reliable propagation methods and silvicultural regimens are only poorly known (Schulte, 2002). In Leyte, Central Philippines, for example, detailed field exploration over several years was needed to “discover” some of the species with greatest potential for agroforestry, which were little known to science and often geographically restricted, although locally highly preferred and offering considerable potential for tree planting (Photo 1.6). While native species are not risk free, and can alter seed flows into neighbouring areas, they do not have the same potential for catastrophic invasion. A switch of philosophy from promoting species as exotic across the tropics to promote greater use on local tree diversity, could improve the problems associated with introductions (Leaky and Simons, 1998).

Photo 1.6. GTZ-LSU “rainforestation” experimental site in Leyte (Central Philippines)

Despite the commercial value of native tree species little information exists on their silviculture. Because of this lack of knowledge and reliable instructions for reforestation on unproductive wasteland and rehabilitation of degraded forest ecosystems with native tree species is still only carried out on a relatively small scale (Shulte and Schöne, 1996). To define even preliminary standards for rehabilitation on the Visayas/Philippines and judge whether or not locally accepted agroforestry practices with native tree species offer a sustainable and profitable land use option; the following attempts are made in this thesis in the form of individual studies. This requires first an appropriate definition of the overall study hypothesis and objectives.

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2. THESIS HYPOTHESIS AND OBJECTIVES

1. Background

This thesis was elaborate within the framework of the Smallholder Agroforestry Options on Degraded Soils (SAFODS), EU funded project (No: ICA4-CT-2001-10092), in close collaboration between the Department of Forestry from University of Cordoba, Spain and the World Agroforestry Centre (ICRAF). The project addresses aspects of sustainable and intensified food production and investigates ways to increase short and long-term profitability of fragile soils of small-scale farmers in South East Asia. These objectives fall under the INCO EU call for ‘Research for Development: Tools for sustainable development’ and specifically section ii) ‘Technologies for sustainable plant and animal production: building blocks for improvement’. The project supported agroforestry development projects in Indonesia and Philippines managed by national research institutes, promoted by NGO’s and supported by an international research institute and European research organizations. Table 2.1 describes the project consortium and what were the interrelationships between partners and activities.

Table 2.1. Project consortium and interrelationships between partners and activities

Partner institution	**1. Farmer typology**	**2. Tree-site matching**	**3. Tree-crop interactions**	**4. Improved options**	**5.Risk / profitability**
1. Wye College (UK)			xi,p	xi,p	
2. Brawijaya Uni. (Indonesia)		Xi	Xi	xi	
3. Lampung Uni. (Indonesia)	Xi				Xi
4. UPLB Uni. (Philippines)	Xp	xp	Xp	xp	xp
5. INRA (France)			xi	xi	xi
6. Cordoba Uni. (Spain)	**xp**	**xp**		**xp**	**x**
7. ICRAF (South East Asia))	xi,p	xi, Xp	xi,p	Xi,p	xi,Xp

(Note: X_i and $\mathbf{X_p}$ indicate task coordination for Indonesia and Philippines, respectively; x_i and x_p indicate active task participation in Indonesia and Philippines, respectively).

Originally two representative degraded regions were selected as the study area: i.e. Claveria, Northern Mindanao (Philippines) and Pakuan Ratu, Southern Sumatra (Indonesia). Based on the experience of the author of this thesis and with the aim to extrapolate/validate the work done by the rest of the project partners in those areas, University of Cordoba decided to open a new research site located in the Leyte Island, Visayas, Central Philippines. The upland agroecosystems of the central Philippine islands are among the most highly stressed and degraded in the region and the rural population in this part of the Philippines among the poorest in the country. The Visayas Region is also characterized by unique constraints of farming in shallow-depleted-calcareous-soils and typhoon-prone environments. Therefore, the risk that poor smallholder have to assume to introduce tree species that are not adapted to these environments is simply too high.

The improved potential for C sequestration of such agroforestry based systems with minimal soil disturbance could have a significant contribution to allaying rates of atmospheric carbon dioxide accumulation and assist in delaying changes in global climates. Development of sustainable approaches to agricultural production and efficient use of natural resources are common goals of all of the nations involved in the project as are reductions in environmental pollution and soil erosion, with the additional benefits of reductions in siltation of dams and rivers.

2. General Hypothesis and Objectives

The project was designed to gain a better understanding of the current land used decisions that lead to rapid conversion of tropical forest, shifting the forest margin, and the slow process of rehabilitation and development of sustainable land use practices on lands deforested in the past. The overall SAFODS hypothesis was "in tree-depleted tropical landscapes with poor soils farming systems purely based on annual food crops are not sustainable, but a transition into tree-based farming is feasible and offers better prospects".

Linked with the overall project hypothesis but trying to narrow the scope of research, this thesis set its own **general hypothesis** as follow:

Using native timber trees for recovering degraded landscapes can result in land use that is both sustainable and productive.

Three main requisites need to be test to answer the overall hypothesis. Are timber based agroforestry systems with native tree species…?

(i) Socially acceptable

(ii) Biophysically feasible

(iii) Economically profitable

In order to answer those general questions and guide the work of the study five specific questions were formulated:

1- Which is the Social Domain where timber tree farming systems might be able to occur?

2- Where is the best location to plant native timber trees across the agricultural landscape?

3- What specific scientific information exist about promising native trees species?

4- What are possible agroforestry scenarios using native timber trees?, and

5- Will native timber based agroforestry systems offer better economic prospects?

At the same time, through answering these questions the **general objective** of this study will be achieved: "*close knowledge gaps and provide a better understanding of smallholder timber-based agroforestry systems using native species*".

Conceptually, the study is approached from three different perspectives: Farmers; Trees; and Systems. This framework should provide a holistic vision of the smallholder mode of timber production and the components that influence the overall behaviour of the system (Figure 2.1).

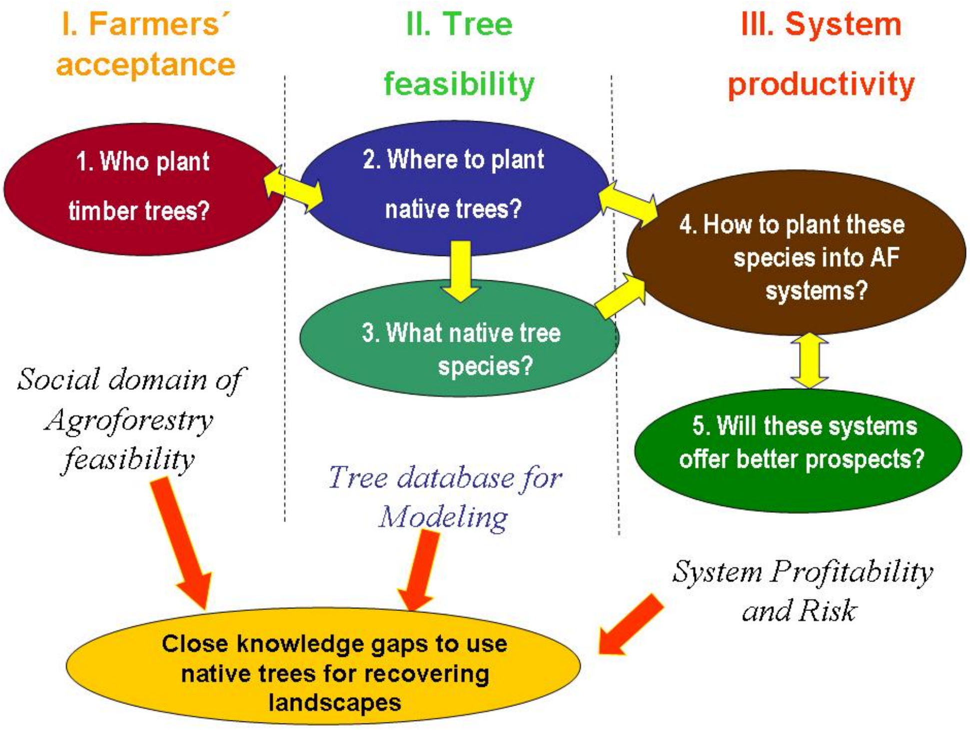

Figure 2.1. Thesis overall framework and flow-chart of the study

3. Specific Hypothesis and Objectives

Based on the above thesis framework, a set of **specific hypothesis and objectives** were developed. Table 2.2 gives an explanatory overview of the interrelation between specific hypothesis and objectives that guided and structured the study.

Table 2.2. Interrelations between specific hypothesis and objectives for each individual chapters/studies

THESIS	HYPOTHESIS	OBJECTIVES
Chapter3	I. Timber tree based farming systems are not feasible for all farmers and conditions and a thorough understanding of how farmers use their available environmental, land, labour and capital resources is necessary to comprehend farmers´ decision making process.	1. Find out the Social Domain in which timber tree planting, as a “particular” agroforestry technology, is feasible.
Chapter4	II. A quantitative system for tree-by-site matching can be developed to assist farmer-specific choices to better recognize and utilize agricultural landscape niches.	2. Test a simple set of indicators of suitable site quality that will help farmers to judge whether a given tree & site combination will be productive.
Chapter5	III. Lack of scientific knowledge of native tree species in relation to tree properties and parameters that can be measured non-destructively constrains the utilization of exiting simulation models for further analysis.	3. Construct a tree database of selected tree species that will allow and improve existing model utilization.
Chapter6	IV. An existing tree-soil-crop simulation model allows evaluation of feasibility and sustainability for realistic farm situations through the generation of a large number of site-specific farmer management strategies.	4. Evaluate the feasibility and sustainability of selected timber based agroforestry systems in relation to biophysical indicators.
Chapter7	V. Timber based agroforestry systems will offer better economic prospects than monocropping scenarios in terms of profitability and economic risk.	5. Assess how robust and buffered from external viability are timber-based system compare to monoculture scenarios.

4. Thesis structure

The five specific hypothesis and objectives presented in Table 2.2 were the entry point of five individual studies, presented in this dissertation in the form of individual chapters. Thus, Chapter 3 presents the results from the socio economic survey conducted among smallholder in four different upland communities revealing which are the major factors influencing farmers capacity and intention to plant timber trees. This result defines the social domain where all the rest of biophysical and economic research presented in this dissertation will be based. Chapter 4 presents data on where farmers are actually planting native timber tree species across the agricultural landscape and evaluates these results in relation to tree growth performance. These results allow initial conclusions on whether a tree-site combination will be productive for farmers based on the available scientific information. In close relation with these results, Chapter 5 describes selection of the most promising native tree species and develops a parameter set for those species utilizing destructive and non-destructive methods which will allow further analysis using model simulations tools. Chapter 6 presents the result from model simulations and evaluates the feasibility and sustainability of a wide array of possible management options. Trade-off analysis between tree growth and crop yield is presented in a simple and innovative format and will be the basis for final discussions. Chapter 7 converts biophysical model simulations results into economic values (using external price data) and evaluates the profitability and risk resilience of each system under different macroeconomic conditions. Overall thesis conclusions are discuss in Chapter 8, where the consolidation of each individual chapter results will lead to synthesized what is needed to facilitate the forest transition that was explained in the initial introduction. The focus of this final chapter is on the policy and economic determinants that the Philippines might have to pass through to improve their natural resources.

3. WHICH IS THE SOCIAL DOMAIN WHERE TIMBER BASED SYSTEMS MIGHT BE ABLE TO OCCUR?

Main factors influencing farmers´ capacity and intention to plant timber trees

Abstract

A thorough understanding of how farmers use their available environmental, land, labour and capital resources to make decisions about whether to invest in agroforestry or another available land use alternative would help extension agents to better support and promote tree planting technologies appropriate to the diverse conditions of upland farmers. Thus, the main objective of this study is to find out the social domain in which timber tree planting, as a "particular" agroforestry technology, is feasible. Data was gathered from a household survey, with a total of 148 respondents in four different rural communities in Leyte Province (Central Philippines). Data was analysed using logistic regression tools from an econometric statistical model. Household level results revealed that the outcome of the decision making processes basically depends on the availability of biophysical resources rather than socio-cultural or economic factors. They suggest that timber-based land use systems have no chance as long as open-access forests still provide for the resource below economic replacement cost. In particular the level of land resources controlled by the household, in terms of the total area and number of parcels managed by the household and the land ownership security stood out as the main factors that affect farmers' intention to plant timber trees. The presence of remaining open access to surrounding natural forest is negatively associated with farmer tree planting. Other cultural, demographic and economic factors appear to have a relatively small effect on farmers´ tree planting decisions and behaviour. These results are consistent with other finding of previous studies in agroforestry, agricultural and forestry practices in the Philippines.

1. Introduction

Once trees with commercial value are harvested, these forests are slashed and burnt by a rapidly growing rural population in search of agricultural land for their subsistence and commercial activities (Garrity *et al.*, 1997). Deforestation has also disrupted the economic development of timber-producing nations for which forests were a major source of employment and income. A number of countries (i.e. Philippines and Thailand) where once "inexhaustible" forests resources grew are now net importers of timber (ITTO, 2001). World demand for timber and fibre based products will continue to rise, expecting to reach 5 billion m^3 per year by 2010 (FAO, 1998). As the few more accessible remaining forests become strictly protected and timber extraction and forest conversion continue in remote and less accessible areas, there are growing concerns about the cost and adequacy of existing wood supplies for meeting future timber demand (Sedjo, 2000).

Rural families in the Philippines are deprived of fuel wood, timber and forests resources necessary for their subsistence and their livelihood. Incentive schemes to encourage farmers´ participation in timber tree planting activities have not been able to draw a genuine reforestation program (Bertomeu, 2004). The failure of subsidy-driven generic reforestation activities and, by contrast, the success of spontaneous tree growing on farms suggest that farmers´ involvement in tree planting is mediated by the individuals´ unique land, labour and capital endowment and socio-cultural conditions (Garrity, 1997). Most reforestation projects in the Philippines, and elsewhere, have been designed on the assumption that farmers would plant trees to satisfy their needs for tree products and income (Photo 3.1). Instead, farmers plant trees in response to the household's broader requirements and the resources and livelihood strategies available to satisfy them (Raintree, 1991). To effectively support wider dissemination of timber based farming systems there is a need to understand the various factors explaining why and how smallholder farmers produce trees, and their perception of the role that trees planted on farms play in their livelihood (FAO, 1994).

Photo 3.1. Farmer collaborator who is an active timber tree planter

Many researchers and extension personnel from throughout the world have argued that decision-makers and extension providers need to understand the variety of socio-economic circumstances and value systems of the various sectors in rural communities (Roshetko and Evans, 1999). It is desirable to have extension personnel consider the individual circumstances of landholders; yet, policy-makers cannot hope to take every individual into account when designing extension programs. They have to find a means to identify and describe the diversity by identifying, if possible, patterns of varying needs, behaviours and socioeconomic circumstances in the community and the relationships between them (Emtage, 2004).

The environment in which farmers are living provides opportunities and constrains which influences their decision making process and their households objectives (Arnold, 1997). Previous studies conducted in different tropical countries provide indications of what factors influence smallholders' upland farmers decisions to plant trees and how they interact (Dewees, 1992; Godoy, 1992; Roshetko and Evans, 1999; Adesina and Chianu, 2002; Bannister and Nair, 2003; Bertomeu, 2004; Emtage 2004). Factors related to land resources are among the most important determinants of agroforestry innovations adoptions in general and tree planting in particular. Among them, security of land tenure have been often cited as a requirement since land ownership gives farmers complete control and rights over the land and tree resources (Garrity, 1997; Arnold, 1997; Huxley, 1999). However, tree planting may occur for example in situations where farmers are simply given use rights, as described by Dewees (1992). Farm size is another important land-related factor influencing tree growing. In the context of subsistence farming, one may expect a large portion of smaller farms planted to staple crops whereas farmers with larger landholdings may be able to devote some land for tree planting without the risk of interfering with food crops (Caveness and Kurtz, 1993).

Tree growing decisions are also affected by farm biophysical characteristics and other factors related to land productivity. Expansion of tree growing has been observed in response to declining soil productivity as a result of erosion and fertility depletion. On the other hand, increasing the productivity of staple crops has helped to reduce pressure on the land for subsistence food production and thus to increase the area occupied by tree crops (Caveness and Kurtz, 1993). The location of the farm in relation to the homestead and the road network are also factors that may influence tree planting on a particular farm parcel since proper access is a requirement for harvesting, loading and transporting heavy tree products (Emtage, 2004).

Besides farmers' resources, several studies have also emphasized the influence on tree planting of individuals' personal characteristics such as gender (Adesina and Chianu, 2002), farmer's age i.e., older farmers are more likely to plant trees because of low labour requirements (Bannister and Nair, 2003; Dewees, 1992), educational level (Sunderlin, 1997) and personal behaviour, like for example progressiveness (Mahapatra and Mitchell, 2001), or enterprising attitude and collective co-operation (Pascicolan *et al.*, 1997).

Farmers' wealth status has been found to increase the likelihood of adopting agroforestry (Mahapatra and Mitchell, 2001) and to be a good predictor of farmer participation in social forestry (Sunderlin, 1997). Farmers may expand the area occupied by tree if cash is available to them (Photo, 3.2), either in the form of credit, or from off-farm sources (e.g., remittances) (Hyman, 1993). Moreover, when family labour is engaged in off-farm employment, farmers are more likely to invest in tree planting as a low-labour land use strategy (Dewees, 1992; Godoy, 1992; Thacher *et al.*, 1997).

Photo 3.2. Farmer who is starting to integrate timber trees in his farm

The identification of potential timber-tree planters among upland farmers requires a theoretical basis to define the relationships between factors thought to influence their behaviour. Obviously the description of a typology of farmers based on a single criterion, such as land size, is of little use if this cannot be related to other differences between the types, including, for example, the level and sources of income to the farmer, differences in farming activities, family structure, land management objectives and more (Emtage, 2004). Raintree (1991) recommended the definition of a set of internally homogenous user groups as a starting point for the design of any agroforestry systems. Tree growing technologies can then be matched to the user groups, and finally tree species to the technologies. The criteria recommended by Raintree, are all readily identifiable characteristics of rural households, their enterprises and their landholdings. These criteria are relatively easy to measure and, when used to segment the population, are likely to provide greater insight into the variations in the suitability of different types of households than would be the case if population averages were used to assess the situation.

Farmer decisions to try ‘new’ land use options (such as the inclusion of timber trees with food crops) are complex in nature and require knowledge (human capital) of the likely consequences (trees and crops competition), supportive village level institutions (social capital), as well as availability of suitable land and in-situ tree germplasm (natural capital) and opportunities to invest time and money (financial capital) (van Noordwijk *et al.*, 2001). Thus, the main objective of this study is find out the specific conditions in which timber tree planting, as a “particular” agroforestry technology, may be applicable in the Visayas (Central Philippines).

2. Material and methods

2.1. Study site: Leyte province

The upland agro-ecosystems of the Visayas, central Philippine islands, are among the most highly stressed and degraded in the region and the rural population in this part of the Philippines is among the poorest in the country (Schulte, 2002). The Visayas Region is also characterized by unique constraints to farming in having shallow-depleted-calcareous-soils in a typhoon-prone environment. The island of Leyte forms part of the Eastern Visayas, Region VIII[4]. It is located south-east of the main island, Luzon, and is the 8th largest of the Philippines archipelago (Figure 3.1). Consisting of two provinces, Leyte and Southern Leyte, it has a total land area of about 750,000 ha. Leyte province consists of 41 municipalities and 1,641 *barangays*[5] (Groestschel *et al.*, 2001).

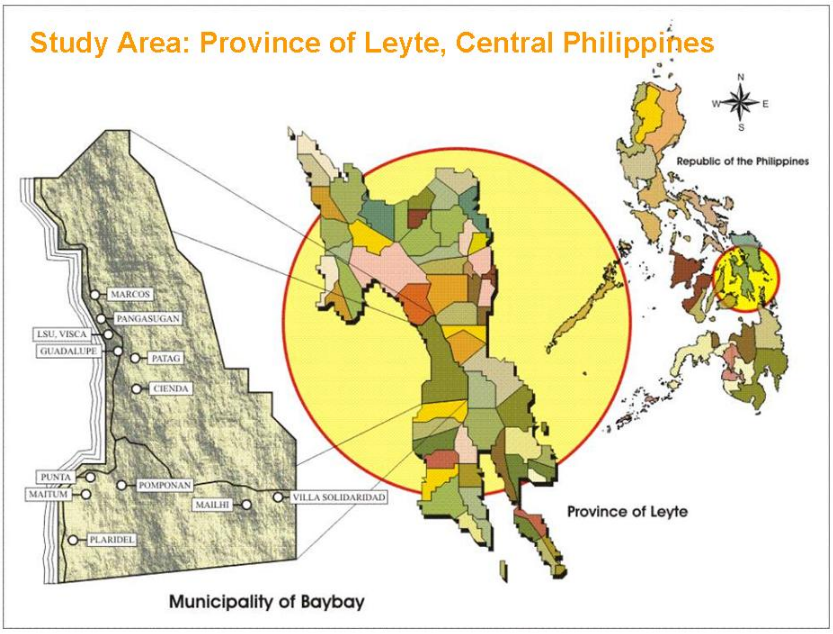

Figure 3.1. Location of study area, Leyte Province, Central Philippines (Source: Leyte State University, GIS laboratory 2001)

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[4] Region VIII is composed of three Islands: Samar, Leyte and Biliran.

[5] *Barangay* was formerly officially called *Barrio* and derived from the Malay word *Balangay*, meaning a type of sailboat. Thus, the word historically refers to the small, independent, and “clannish” settlements established by the Malay ancestors of the Filipinos. Today the barangay represents the smallest division of self government. Several barangays make up a town or a municipality. Thus they may appear as a town quarter or also as a village.

In the year 2000, Leyte's population registered was 1,972,446 persons with a density of 210 persons/km^2, a growth rates from 1995 to 2000 of 2.63 % and the average household size are 5.01 persons (NSCB, 2001). Leyte's economy basically revolves around agriculture. The main source of income for the majority of the population comes from the production of crops, livestock and marine products. The average annual family income in 2000 was PhP[6] 67,291. The annual per capita poverty threshold for Region VIII was PhP 10,783 for all areas (urban and rural). The poverty incidence of families (average 5.1 persons) is 50% for rural families (Table 3.1).

Table 3.1. Average annual income and poverty thresholds in Leyte (Source: NSCB, 2001)

POVERTY INCIDENCE	QUANTITY	UNIT
Average annual family income	67,291	Philippine Peso (PhP)
Annual per capita poverty thresholds	10,783	Philippine Peso (PhP)
Urban	12,011	Philippine Peso (PhP)
Rural	8,728	Philippine Peso (PhP)
Poverty incidence of families	43	%
Urban	27	%
Rural	50	%

The majority of Leyte´s farmers have land holdings of less than 1 ha up to 5 ha tilled land. A census of the Bureau of Agricultural Statistics (BAS) form 1999 showed that 93% of the farms in Leyte belong to this cluster. Since the agrarian reform generally focuses on distributing holdings larger than 5 ha, it can be assumed that the percentage of large land holdings has decreased.

In the past decades forests were one of the most significant natural resources of Leyte. Large- scale logging operations and the extensive conversion of forest land into agricultural areas, especially into coconut and abaca (*Musa textilis,* a banana relative, grown for its fibre) plantations, can consider the main factors for this forest decline. To determine how much of the island area is currently used for agriculture is quite difficult as there is no actual data available on the land use in areas classified as forest lands. The major crops grown on the island are coconut, rice, abaca, sugarcane, cassava, banana, sweet potato and corn (Table 3.2). Coconut production in Leyte plays a significant role in terms of land use and land cover, as well as in terms of cash income. Food crops mentioned usually remain in local markets or used for home consumption.

Table 3.2. Major crops grown in Leyte Province (Source: BAS, 1999)

CROP	PRODUCTION (MT)	AREA HARVESTED (HA)	% LAND AREA
Coconut	574,302	159,555	21.4
Rice (irrigated) – grain	203,682	69,800	9.4
Rice (rain fed) – grain	70,711	34,374	4.6
Corn – grain	23,379	39,085	5.2
Abaca	20,265	20,933	2.8
Banana	303,332	14,128	1.9
Sweet potato – tuber	60,480	10,673	1.4
Cassava – tuber	33,513	9,281	1.2
Sugarcane - stem	528,135	8,851	1.2

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[6] Philippine Pesos, 1 Euro= 63.1 PhP (exchange rate, October 2006)

2.2. Source of data

Data used for this study was gathered from a household survey that was part of a Participatory Rural Appraisal (ANNEX 1), with a total of 148 respondents in four different rural communities in Leyte Province (Photo 3.3). Households were selected randomly in each community (SSC, 2001) as there was not information from tree planters to a priori stratify the population. The four municipalities and communities were selected based on two main variables: the existence of remaining open access to natural forest (with *vs*. without natural forest) and the type of soil (productive *vs*. degraded) (Table 3.3). This information was gathered using existing maps of the study area (Leyte State University, GIS laboratory 2001).

Photo 3.3. Individual farmer interview as part of the PRA conducted for the study

Table 3.3. Final 4 sites selected for the studying in Leyte Province

SELECTION CRITERIA	LEYTE PROVINCE Municipality	 Community
Degraded soil - with forest	Hinunangan	Calag-itan
Degraded soil - without forest	Tabamgo	Manlawaan
Productive soil - with forest	Inopacan	Cabulisan
Productive soil – without forest	Tomas Oppus	Mapgap

The information from the PRA was consolidated (in anonymous form) into the Household and Tree database in Leyte province (Santos-Martin *et al.*, 2002). The mentioned database includes biophysical and socioeconomic household characteristics and it was structured in four levels of information: (i) site characteristics, (ii) demographic and cultural aspects, (iii) landholding and labor resources and (iv) economic factors. Specific topics covered in each level of information are described in Table 3.4.

Table 3.4. Topics covered and variable description for each level of information of the model.

INFORMATION LEVEL	**TOPICS COVERED**	**VARIBLE DESCRIPTION**
Site Characteristics	-Soil characteristics -Access to forest -Accessibility	-Productive or Degraded -With or without open access to forest -Distance to nearest market
Demographic and Cultural aspects	-Number of HH[7] members -Age -Education level -Migrant -Tree experience	-Including working and dependent -Of HH head -Of HH head -Province or Region level -Years in tree farming
Landholding and Labour resources	-Total area manage -Number of parcels -Area owned -Working HH members -On farm working members	- Area Owned and Tenanted -With different land-use systems -Excluding tenanted and rented -On-farm plus off-farm members -Excluding off-farm members
Economic factors	-Total HH income -On-farm income - Land productivity	-On-farm and off-farm resources -Agricultural and tree products - Income per unit of land

2.3. Model building

The process of model building began by defining the response variable: which farmers plant timber trees. Farmers considered to be ‘timber planters’ were those who have planted within their land resources (owned or as tenant) any kind of timber tree (exotic or native) recently or in the past. The process of assessing a “reasonable” set of independent variables that can explain the response variable was based on the results of the exploratory data analysis. The analysis consisted of “forward selection”, to assess the effects of new variables and their interactions, and “backward elimination”, to drop unimportant terms and to see whether effects were masked by possible correlations introduced by other variables. The contribution to the model of each of the independent variables introduced was assessed by chi-squared test. The analysis aimed at building a model without a large number of variables but with an acceptable prediction rate (low residual rate).

Because the response variable is binary / categorical (0/1: plant or not plant timber-trees) a model was used that handles continuous and categorical variables correctly. As a result from the iterative process of variable selection, a final set of 15 independent variables was chosen which reflected hypotheses of the strongest influence on farmers´ decisions to plant timber trees (Table 3.5). For each independent variable the effect (positive or negative) on the response variable was expressed a priori. This approach provided a test which variables have the strongest relationship with the response variable and also tested if the initial hypothesis of the effect for each variable could be supported at specified level of statistical significance.

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[7] HH: abbreviation of Household

Table 3.5. Final set of independent variables used in the model

RESPONSE VARIABLE	VARIABLE TYPE	DESCRIPTION / UNIT	HYPOTHESIS EFFECT
Plant timber-tree	Categorical	0 or 1 (0 not planting, 1 planting)	
INDEPENDENT VARIABLES			
Soil	Categorical	0 or 1 (0 degraded, 1 productive)	Negative
Forest	Categorical	0 or 1 (0 No forest, 1 Forest)	Negative
Accessibility	Continuous	Distance (Km) to nearest market	Negative
Migration	Categorical	0 or 1 (0 No migrated, 1 Migrated)	Negative
Education	Categorical	0 or 1 (0 No education, 1 Education)	Positive
Age	Continuous	Respondent age (Years)	Positive
Tree-Experience	Continuous	Experience in tree-farming (Years)	Positive
Total Area	Continuous	Total number of hectares	Positive
Parcels size	Continuous	Total area / Number of parcels	Negative
Area Owned	Continuous	Area owned / Total Area	Positive
Work	Continuous	Working HH member / Total Area	Negative
Labour	Continuous	Working HH member / HH members	Negative
Income	Continuous	Total HH income / Working HH members	Negative
Farm-Income	Continuous	Farm Income / Total HH income	Negative
Productivity	Continuous	Farm Income / Total area	Negative

The “Soil” and “Forest” variables describe the general site characteristics in regards to the status of the soils and remaining open access to forest resources at the village level. It was hypothesized that good soil condition will enhance timber tree planting activities, while if natural forest still remained in the area it would have a negative effect on farmers motivation to plant timber trees. “Accessibility” refers to the distance from each farm to the nearest market where tree product could be sold; it was hypothesized that a greater distance would discourage farmers to plant trees because of less market possibilities.

Cultural variables are: “Migration” which identifies farmers who have migrated from different municipalities or regions in the past, it was hypothesized that migrant farmers have less interest in trees because they are usually focused on subsistence farming activities. “Education” classified farmer that have studied beyond elementary school; it was hypothesized that farmers with studies will be more open to new initiatives. “Age” of respondent was hypothesized as having a negative effect because younger farmers seem to be more active and innovative. “Tree experience” refers to the number of years that respondents have been engaged in timber tree planting, it was hypothesized that farmers with more experience are more knowledgeable and better tree planters.

Household land resources were included in the model through: “Total area” refers to the total number of hectares that are managed by the household (including area owned and used as tenant); it was hypothesized that the larger the area managed, the easier it would be to devote a portion to timber trees. “Parcels” refers to the number of parcels in the total area managed by the household; it was hypothesized that with a bigger number of parcels it would be easier to plant timber trees. “Area owned” is the proportion between the area owned by and the total area managed by the household; it was hypothesize that farmers with more area owned will have more freedom and right to decided if they want to engaged on planting trees.

Since tree cultivation is not as labour-demanding as annual cropping, it was hypothesized that timber planting is likely to be a viable option for labour-constrained household and more attractive than other land used alternatives such as grass and bush fallows. Demographic selected variables are: “Work” represents the relation between the numbers of working household members on farm with the total area they manage; it was hypothesize that if the average area that each member have to manage is small enough they will tend intensify agricultural land use systems. “Labour” is the relation between the on-farm working members with the total number of members; if this relation is small it means that exist some labour constrains and therefore tree planting systems seems to be a good land use alternative.

The last three variables explain household economic status. “Income” is the relation between the total household income (farm and off-farm income) and the number of working household members; it was hypothesized that if the household strategy is to maximize short term profitability with the exiting labour resources, they will tend to not plant timber trees. “Farm Income” is the proportion between yearly farm income and total household income; it was hypothesized that if farmers depend basically from farm resources then they will focus on agricultural crops. “Productivity” is the relation between the farm income and the total farm area managed; it was hypothesized that if the household strategy is to maximize profitability given their existing land resources they will tent to not plant timber trees.

2.4. Social Analysis

Data was analysed using logistic regression tools with the econometric statistical software package STATA 9.1 (www.stata.com). To run the model it is necessary to use the logit command and the output that it automatically generates is a list of coefficients for each independent variable. The first column (dy/dx) shows the marginal effects in *odds ratio* and the strength of the independent variables when the dependent variable changes from 0 to 1. The odds ratio describes binary response outcomes for explanatory categories, indicating that there are farmer planters in the explanatory category 1 fore every one non-planter in the category 2. Marginal effects are calculated when the dependent variable is at its mean value. If the coefficient is negative, the odds ratio is less than 1, and then more of that covariate makes the outcome less likely (holding the values of the other covariates constant). If a coefficient is positive, the odds ratio is more than 1, and then more of that covariate makes the outcome more likely (holding the values of the other covariates constant).

After comparing and interpreting the resulting odd ratios, few independent variables were selected as having the greater influence on timber tree planters based on which had a p-value < 0.1 (10 % significant level respectively). The P-value gives the probability of getting as large a coefficient value (and corresponding odds ratio) in the sample when in fact the real coefficient in the population is 0. Is important to remember that p-value does not necessarily reflect the importance of a covariate; it reflects measurement error and sample size.

3. Results

3.1. Independence variable text

Once all variables from the model were defined and categorized, major patterns and relationships between the large numbers of independent variables were first examined by performing a scattered plot matrix analysis which shows the relationship for each possible pair of variables. As can be seen in Figure 3.2 no strong correlations were found among the variables used, satisfying the assumption of independence in the final model.

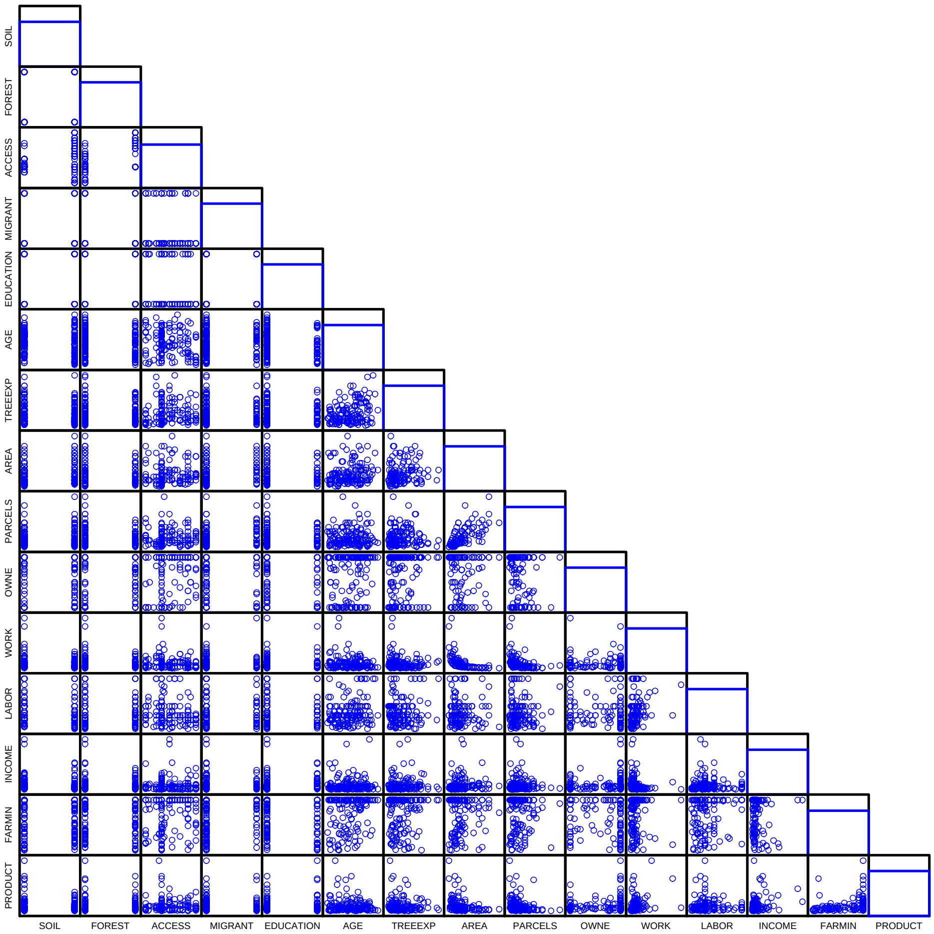

Figure 3.2. Scatter plot matrix to test the independence of model variable set

3.2. Social domain for timber tree planters

Logistic regression results in Table 3.6 include the change in the probabilities when the independent variable varies from its minimum to its maximum. The second column (dy/dx) shows the change when the independent variable varies for 0 to 1. This is the most useful when analysing categorical variables. The third and fourth columns show the change in probabilities when the independent variable varies one unit in real value or in standard deviations, respectively. The last column presents the marginal changes of the independent variable. All this values were calculated at the predicted probability when the independent variables equal the respective mean values.

Table 3.6. Model results with logit estimates of likelihood for timber tree adopters
Ordered Logistic regression (Number of observations = 148)
Prob > chi^2 = 0.0757 LR chi^2(15) = 23.41 Log likelihood = -83.940
Pseudo R^2 = 0.1224 Marginal effects after logit y = .38161705

VARIABLE	DY/DX	ST. ERR.	Z	P>|Z|	[95% C.I.]		X
Soil	.1516	.1011	1.50	0.134	-.0466	.3499	.5633
Forest*	-.1995	.1141	**-1.75**	***0.080**	-.4233	.0242	.4577
Accessibility	.0189	.0122	1.55	0.122	-.0050	.0428	9.8450
Migration	-.1056	.1051	-1.00	0.315	-.1702	.1004	.2042
Education	.0552	.1150	0.48	0.631	-.0057	.2807	.2605
Age	.0024	.0041	0.58	0.559	-.0090	.0105	53.2100
Experience	-.0015	.0038	-0.40	0.690	-.0064	.0059	16.4700
Total Area*	.0395	.0234	**1.68**	***0.092**	-.3157	.0856	3.8200
Parcels**	-.1696	.0745	**-2.28**	****0.023**	.0052	-.0234	1.2960
Area Owned**	.2352	.1173	**2.00**	****0.045**	-.1023	.4651	.6600
Work	.0103	.0574	0.18	0.858	-.2466	.1229	.8689
Labour	.2167	.2364	0.92	0.359	-.0000	.6802	.3848
Income	-4.96e-06	.0000	-1.44	0.149	-.3860	1.8e-06	12670.7000
Farm Income	-.0565	.1684	-0.34	0.737	-.3860	.2735	.7499
Productivity	8.53e-08	.0001	0.01	0.991	-.0000	.0000	6718.0700

(Note: * and ** indicate statistical significant at 10% and 5% level respectively)

Based on these results, it can be concluded that the main factors that influence farmers´ decision to plant timber trees are linked with availability of biophysical resources, while household socio-economic, demographic and cultural factors turn out to have less influence. More specifically model results, suggests that timber trees planters are only significantly influenced by mainly two main factors in order of importance:

1. Availability of land resources in terms of total area, number of parcels and ownership; and
2. The site characteristics in terms of accessibility to forest resources in the surrounding area.

All variables included in the model describing household land resources stood out to be statistically significant and with the expected sign which they were initially hypothesized. The positive values from the odds ratio coefficient of “Total area” manage and proportion of “Area own” indicates that exist a direct relation between these variables and the intention to plant timber trees. The negative sign from the “Parcels” variable should be interpreted as given a “Total area” if the number of parcels increases it will be easier to devoted at least one of those parcels to agroforestry or purely tree plantations land use systems.

From the site characteristic level, the only significant variable stood out to be “Forest” representing the open accessibility to remaining forest resources in the area. The negative sign form the “Forest” variable implies that the likelihood of adoption decreases if the existence of forest resources still remains in the area. This can be easily interpreted as farmers living close to natural forest do not fell the necessity to plant timber-trees on their farm because they can freely collect their necessary tree products from existing forest resources.

Rest of variables included in the model turn out to have lower influence. None of the demographic, cultural and economic factors were found to be statistically significant. However, this shouldn’t be interpreted as these variables are not important concerns but within the model they showed less influence on farmer’s timber tree planting behaviour.

The influence of variables as “Soil” and total household “Income” is unclear from the results. Although their signature was in the direction hypothesized, the variability on the data did not rule out the null hypothesis of no effect. Total household “Income” (including on-farm and off-farm sources) suggests an opposite incentive to timber tree adoption. In fact, the negative sign of its coefficient implies that if the economic situation increases (usually from off-farm sources) they will progressively abandon agricultural activities, which at the end it might be ultimate goal of many farmer for their future generations.

The relation between availability of family labour resources “Work” and “Labour” and response variable was not captured in the model. There is, however, suggestive evidence of an interactive effect between these variables and the intention to plant timber trees reflected in the positive sign of their coefficient. Contrary to expectations, variation in “Farm Income” and land “Productivity” is not associated with the adoption of trees. Only in the case of “Experience” negative values form the odd ratio coefficient contradict initial hypotheses implying that the likelihood of adoption decreases as farmers tree experience increases.

4. Discussion

In many developing tropical countries, the intensification of agricultural activities is clearly linked to the process of declining of forest resources. Two main factors have been often identified as having major influence on the expansion of sustainable land use systems: (i) the general open access condition of the frontier, (ii) poor tenure or property land right. Result form this study confirms these ideas and is consistent with previous research into agroforestry, agricultural and forestry practices in the Philippines, and elsewhere (Aguilar, 1986; Ponce and Bangi, 1988; Nigidlo, 1990; de los Angeles and Ygrubay, 1992; Sajise and Briones, 1996; Nasyao and Zara, 1997; Barbier, 1997; Emtage, 2004; Bertomeu, 2004). Hence, targeting forest rehabilitation programs to areas that are already highly deforested and/or have high potential of degradation should be an effective strategy.

It is important to keep in mind that the decision of a household to follow a particular livelihood strategy is the outcome of a fine-tuning of objectives to their possibilities and constraints (van Noordwijk *et al.*, 2001). In practice this means that the decision-making processes at the household level, depends on their available resources (Kragten *et al.*, 2001). Study results showed that smallholder timber-based agroforestry systems have no chance as long as open-access forests still provide for the resource below economic replacement cost. The general open access condition of unoccupied forest land is recognized as a key condition underlying frontier agricultural expansion in many developing tropical countries (Perace *et al.*, 1990; Mahar and Shceneider, 1994; Southgate, 1994). There are two main aspects of this problem (Barbier, 1997). First, there are also households that forego investments in sustainable farming systems on the land that they initially convert and occupy on the frontier, instead choosing to abandon this land as yields decline and migrate to new land further in the forest frontier. Second, many households also migrate to the frontier as rural employment increasingly scarce. Both problems involve essentially related processes, which can be referred to collectively as the incentives for rural households to abandon existing agricultural land in favour of converting and occupying new land on the forest frontier.

Additionally, the lack of secure property rights encourages rapid expansion of frontier agricultural activities by landless smallholders in search for new land. Faced with availability of new land in the form of abundant forest resources, farming households will continue to expand their agricultural activities into the forest frontier until rents are completely dissipated (Barbier, 1997). Study results are in line with this idea, where land ownership and the level of land resources controlled by the household, in terms of the total area and number of parcels, stood out as the main factor that affect farmer’s capacity to invest in sustainable farming systems. It is widely believed that land tenure insecurity under a traditional tenure system leads to socially inefficient resource allocation (Putzel, 1992); because land ownership gives farmers complete control and rights over the land and tree resources. Furthermore, lack of control over public lands may means that initial occupation is relatively easy and cheap, and thus, land resources encourage further extensive conversion of forest land to agriculture.

Past government policy changes have provided non-owners who cultivated public land the opportunity to obtain a Certificate of Stewardship Contract on the land they cultivate, which may ultimately grant them the right to own the land (USAID, 1994). This institutional and policy environment provided the appropriate initial conditions to promote sustainable land use systems in the Philippines. However, given unclear and uncertain individual rights, incentives to invest in land and tree resources may be frustrated (Harrison *et al.*, 2002). Relatively strong individual ownership rights are granted to those who clear communal forests for cultivation. Sands (1998) argue that individual land right acquired through clearance of communal forests tend to diminish over time, if land use is limited to food crops under shifting cultivations (slash and burn). In particular, when land is fallowed, other members to the extend community can claim the right to use this “unused” land. Under such community rules, an individual farmer who has cleared forest land would have strong incentives to plant trees in order to establish secure land rights (Borlangdan *et al.*, 2001).

The economic principle of land use takes as its starting point that land is allocated to the use with the highest land rent (Angelsen, 2007). The rent of alternative land uses is determined by a number of factors such as crop prices, input cost, available technologies, agro-ecological conditions, etc. Many of these depend directly or indirectly on the location of the land. A key aspect of the location is the remoteness, as measured by the distance to markets or cities. This approach was first proposed by Johann von Thünen in 1826. Study results showed that access to markets have a light positive influence on tree planting activities, suggesting that improvements of rural infrastructures like roads encourage more intensive forms of agricultural production system. Road building and insecure property rights in frontier forest areas make forest lands artificially cheap and readily available to farmers. Road building not only reduces the cost of access to these lands by farmers, but also ensures and abundant supply of new land to meet demand (Barbier, 1997).

If we assume that smallholder tree planting is not just a production strategy for maximizing profit but a strategy to respond to farmers’ changing resources and circumstances it will be easy to understand why “labour” and “capital” factors didn’t show a significant influence in the model. In situations where capital and labour are scarce, trees can be planted as a low-input, low-management crop, to make more productive use of land. Trees can also maximize returns to land when farm size and/or site productivity decline below economic levels. Lastly, trees can contribute to risk management through diversification of outputs, avoiding labour bottlenecks and spreading risks (Arnold, 1990). Therefore, the most significant advantage of this wide repertoire of tree production strategies is its flexibility to match farmers’ individual needs and preferences within their specific conditions and changing circumstances (Scherr, 1995).

Other important finding of the study is to evidence that contrary to expectations, “cultural” and “demographic” aspects of household communities have low effect on final farmers´ tree planting decisions and behaviour. These findings are also in line with FMB-FAO (2003) where it was found that in different countries of West Africa not direct correlations were found between tree planters and diverse ethic groups (Kojo, 2003). However, this doesn’t necessarily means that tree farming, has to be promoted in standard extension packages (Garrity and Mercado, 1994), without considering the high degree of variability between and even within households (Raintree, 1991). A thorough understanding of how farmers use their land, labour and capital resources to make decisions about whether to invest in agroforestry or another land use alternative would help extension agents to support and promote technologies appropriate to different farmers. But extension agents should also keep on mind that even if a specific form of a technology turns out to be inappropriate in a given location, the generic principles of the technology might still be applicable (Cramb, 2000).

Before considering the final conclusions of the study, a number of limitations of the study must be noted. Surveyed farmers were classified as adopters (planters) and non-adopters (non-planters) of timber trees after the field inventory. Among the 148 farmers surveyed, it was considered as timber-planters 58 farmers (or 40%) and the rest were considered farmers purely based on agricultural crops. However, 64 (71%) of the non-adopters and all (100%) of the adopters of timber trees had also applied other “specific” tree planting technologies such as fruit trees and/or management of natural regeneration tree fallows. Since farmers can apply these and other “specific” tree planting technologies, within the same set of household and farm conditions, to meet their goals with similar success (e.g., labour-constrained farmers may make a more productive use of fallowed land by planting timber trees, or fruit trees), there has probably been a confounding effect introduced in the model by the large number of farmers classified as “non-adopters” (of timber trees) that are actually tree planters. Ideally, to study the factors influencing the planting of just timber trees (as a specific technology), comparisons should have been made between tree planters (either with fruit and timber trees or only timber trees) with non-planters (neither timber nor fruit trees planted) and/or between planters of fruit trees with planters of both, fruit and timber trees. Other limitation of the study has probably been the “gender imbalance”. Almost all the respondents during the individual interviews were men. For sure the inclusion of more of women responses would have enriched the outcome of the study. Despite the introduced bias in the respondent selection, the results of the study still provide a solid representation of smallholder farmers living in uplands areas.

5. Conclusions

- Study results revealed that main factors influencing farmers´ capacity and intention to plant timber trees basically depends on the availability of biophysical resources rather than socio-cultural demographic or economic factors.
- In particular the level of land resources controlled by the household, in terms of the total area and number of parcels managed by the household and the land ownership security stood out as the most important factors that affect farmers’ decisions.
- The presence of remaining open access to surrounding natural forest stood out as the second most important factor negatively influencing farmers´ intention to plant timber trees.
- These results suggest that timber-based agroforestry systems have no chance as long as land resources and open-access forests still provide for the resource below economic replacement cost.
- Hence, targeting forest rehabilitation programs to areas that are already highly deforested and/or have high potential of degradation should be an effective strategy.
- These results are consistent with other finding of previous studies in agroforestry, agricultural and forestry practices in the Philippines and elsewhere.

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4. WHERE TO PLANT NATIVE TREES ACROSS THE AGRICULTURAL LANDSCAPE?

Tree growth prediction in relation to simple set of site quality indicators

Abstract

The interaction between trees and the environmental site conditions at the landscape level is complex because different tree species have different requirements for growth. The gain in precision to explain the variation on tree growth performance as a function of a set of site indicators was analysed in a step-wise form, increasing its complexity and costs. The starting point of the study was the localization and measurement of planted trees at different farmers´ sites located across the agricultural landscape. Six native timber tree species were commonly found on farmer’s fields and planted under different types of agroforestry systems. Localization of trees to be used for measurement was achieved through individual interviews to assess timing of introduction of trees. A total of sixteen farmers cooperators from Manlaawan, were involved in the study. Native tree species found on farmers fields revealed that have a reasonable growth rate for medium-term timber trees and are very similar to other exotic species as *Swietenia macrophyla* that are widely spread in the Philippines. Nevertheless, the large fraction of the variation in tree performance that could not be explained by the biophysical site indicators measured implies that farmers take considerable risk in planting trees on the basis of current ‘scientific’ knowledge. The complement of ‘site characteristics’ is probably ‘management’, and the low determination of tree growth by site properties may in fact be good news for the farmers.

1. Introduction

Traditionally the focus of agroforestry research has been on interactions between trees and other components of a system, such as crops, soil and climatic factors, on the scale of an individual field or a small section of a landscape (Schroth and Sinclair, 2003). This is gradually changing as better understanding of small-scale processes enables researchers to scale up their results, and as the functions of tree cover manifest at landscape, regional and global scales, as a result of larger-scale patterns and processes, become the focus of research interest (Guindon, 1996). Also, agroforestry practices do not exist in isolation, but interact with other land uses across landscapes (Huxley, 1999). A farmer maintaining a forest garden or shaded tree crop plantation may also have swidden or irrigated rice fields and pasture which occur together within the same landscape and influence the characteristics of this landscape (Nair, 1993). This wider focus of agroforestry research is reflected in a scale-neutral definition of agroforestry as simply “where trees and agriculture interact” (Sinclair, 1999).

Within this wider view of agroforestry, the landscape scale is emerging as a critical unit of analysis (Sinclair, 2001). In many fragmented landscapes trees on farms, provide key elements of the tree cover that determine landscape characteristics, and efforts to understand and develop the role of trees on farms will increasingly focus on landscapes (Bruijnzeel, 1997). Strategic placing of trees in the landscape may prevent, enhance or direct flows of soil, water, fire and organisms across landscapes (van Noordwijk, 1999). The fundamental assumption in agroforestry, that the integration of trees in farming systems and landscapes can increase soil fertility, productivity and sustainability, was initially based mainly on the observation that soil under forest vegetation generally remain fertile and that tree fallow are able to regenerate degraded soils, as occurs in shifting cultivation systems (Nair, 1993). Subsequent scientific research has increasingly produced insights into the mechanisms through which trees affect soil conditions; the counterpart processes, how soil conditions affect tree growth performance, have not often been quantified (Photo 4.1). When designing or improving agroforestry techniques, it is therefore important that the system is matched with the site conditions, rather than assuming that every type of agroforestry will improve site conditions in general (Huxley, 1999).

Photo 4.1. General view of where farmers plant trees across the agricultural landscape

Usually tree-site matching is approached from two different perspectives: trees or sites (Lusiana and van Noordwijk, 2006). The trees' perspective will have the objective to develop suitable site maps for each tree species given its provenance. From the site perspective, efforts will try to list the 'best bet' tree species for each site. But from the farmer's point of view the choice also involves comparison with other options and the main question address from this perspective will be: How can I judge whether a given tree and site combination will be productive? Or, how can I evaluate cost-benefit of modified choice based on better (and more expensive) information? In this study efforts have been focused on the third perspective as a combination of the traditional tree and site approaches (Table 4.1).

Table 4.1. Tree-site matching from three different methodological perspectives

PERSPECTIVE	STEP 1	STEP 2	STEP 3
1. Tree: What are suitable sites for this tree specie (given its provenance)?	Calculate performance relative to 'reference'	Identify 'growth retarding' factors: landscape position, soil type, soil physics, soil chemical factors	Map relative suitability based on combined model for each tree species
2. Site: What are the best tree species for this site?	Derive efficient site typology	Combine relative performance per tree species with expected value for the farmer	List the 'best bet' tree species for each site
3. Farmer: Based on what information can I judge whether a given tree & site combination will be productive?	In Tree – Step 2: calculate stepwise adjusted R^2: what gain in precision can be obtained with more complete information	Compare costs of obtaining various site indicators to the expected gain in predictive power of performance	Evaluate cost-benefit of modified choice based on better information

During the past 30 years, large areas have been 'reforested' in different areas of the Philippine uplands (Garrity and Mercado, 1997). However, survival rate was very low and slow growth of planting stocks was registered all along the country (PCARRD, 1992). This was attributed to the unfavourable growing condition of the site and to failure in selection of appropriate species. Matching tree species to the biophysical characteristics of a site is necessary but not sufficient to ensure adoption; trees also have to be compatible with views, experiences, traditions and economic capacities of the farmers (Scherr, 1997).

Despite the importance of such site-species matching, species selection by farmers appears to be based on other factors (Harrison and Herbohn, 2000). Firstly, farmers strongly favour a species from which high returns have been obtained in the past. Secondly, farmers almost invariably choose a species for which planting material is low in cost and readily available. As a result, most common species found in upland farms in the Philippines are fast growing exotic species as: Gmelina (*Gmelina arborea*), Mangium (*Acacia mangium*), Mahogany (*Swietenia macrophylla*) and Falcata (*Paraserianthes falcataria*). However, new initiatives of agroforestry development are trying to integrate native tree species into agricultural systems because increasing the quality, number and diversity of domesticated trees should enhance agroforestry capacity to fulfil its ultimate potential as a way to alleviate poverty and to mitigate deforestation and land depletion (Leakey and Simons, 1998).

According to Roshetko and Evans (1999) to thoroughly assess the potential of promising and preferred native tree species for on-farm domestication should first take into consideration: plant spacing and pattern, management practice and suitability or growth performance in varying site conditions. The function, patterns and management systems of smallholder timber plantations are markedly different from those found in natural forest, government-sponsored reforestation and plantation forestry (Harrison and Herbohn, 2000). To better serve these functions, trees may be incorporated in various densities and arrangements in existing farm niches (e.g. cropping areas, homestead). This set of interrelated decisions of a tree growing practice will eventually define the attributes of the appropriate tree specie to be selected for on-farm planting to perform the intended function (Raintree, 1991).

Nowadays a number of databases exist that classify trees by their broad climatic requirements and types of use. This information is generally not sufficiently precise to guide local choice of species, where no systematic testing of provenances has been carried out yet (Roshetko and Evans, 1999). A detailed landscape and soil characterization will help identify site specific tree and soil attributes. For example, in undulating landscapes, the tops and crest of ridges, the mid-slope position and the valley bottoms offer very different soil fertility and water supply conditions (Young *et al.*, 1998). This site characterization will thus provide a valuable database for assessing the suitability of specific tree species for such agroforestry systems.

Therefore, the main objective of this study is to provide the necessary basis for smallholder farmers to test selected native trees by site matching to better recognize and utilize agricultural landscape niches. More specifically this study will (i) Measured and described location of introduced native trees across the agricultural landscape (ii) Analysed soil chemical and physical conditions of farmers' sites and (iii) Evaluate gain in tree growth prediction in relation to simple set of site quality indicators.

2. Materials and Methods

2.1. Study area: Manlawaan, municipality of Tabango

The municipality of Tabango is located in the north-western part of Leyte Province (11^{o}18′north latitude and 124^{o}23′east longitude), about 135 km from Tacloban City. It covers an area of 12,920 ha of which 9.28 % are classified as timber land, but only 0.12% is actual forested areas (Groestschel *et al.,* 2000). In year 2000, the total number of inhabitants was 31,433 (population density is 243.7 persons per km^{2}) where agricultural production is the main source of income for the majority of people (NSO, 2001). Profile of Tabango (undated) describe that most parts of the municipality are characterized by moderately to steeply sloping terrain, with slopes of 50% and above being cultivated for annual crop production. Level lowland (10 < % slope) areas are limited to about 25% of the total area. The dominating soil type in the municipality is 'Lugo Clay' that has developed on calcareous parent material (limy shale or marl). The climate is Type IV based on the Corona classification for having no distinct dry and wet seasons. The average temperature is 26.65ºC and the mean annual precipitation is 2,700 mm/yr. Tabango is composed of 13 villages where Manlawaan is one of the most remote and poorest communities within the municipality and province. It has a total land area of 803 ha. which are classified to its existing land use plan as describe in Table 4.2. Manlawaan is also one of the early sites of the Operation Land Transfer of the agrarian reform program from the Philippine government (Torres *et al*., 1986).

Table 4.2. Land use distribution of Manlawaan community (Source: Profile of Tabango)

LAND USE	TOTAL LAND AREA (HA)	% LAND AREA
Annual crops	446	55.4
Perennial crops	123	15.3
Forest land	118	14.6
Grassland / pasture	64	7.3
Built-up	50	6.4

2.2. Searching for planted native trees in Manlawaan

The starting point of the study was the localization and measurement of native trees planted at different farmers´ sites located across Manlawaan´s agricultural landscape. Localization of trees to be used for measurement was achieved through individual interviews to assess timing of introduction of trees. A total of sixteen farmers cooperators from Manlaawan, who have planted native trees species on their farms in the past were involved in the study (Photos 4.2 and 4.3). Six native timber tree species were commonly found on farmer's fields and planted under different types of agroforestry systems (Table 4.3). Growth measurements (DBH and total height) were measured during field visits.

Table 4.3. Total number of trees measured for each species found in Manlawan

SCIENTIFIC NAME	COMMON NAME	FAMILY	NUMBER
Shorea contorta Vid.	White lauan	Dipterocarpaceae	132
Vitex parviflora Juss.	Molave	Verbenaceae	143
Pterocarpus indicus Willd.	Narra	Fabaceae	127
Artocarpus heterophyllus Lam.	Nangka	Moraceae	115
Dracontomelon dao Blanco.	Dao	Anacardiaceae	85
Afzelia rhomboidea Blanco.	Tindalo	Caesalpiniaceae	72

Photo 4.2. Farmer collaborator intercropping native trees with food crops

Photo 4.3. Farmer collaborator planting native trees in association with perennial crops

2.3. Soils sampling of farmer's sites

A combined analysis of soil physical and chemical properties were performed on farmers' collaborators farms only for the top layer as it is the most dynamic layer (Hairiah *et al.*, 1992). Soil samples were collected from the three parts of every farm that includes the upper, middle and lower slope. Soil samples were taken at 20 cm depth without litter for at least one kilogram per hole; they were placed in separate plastic cellophane bags and properly labelled. Samples collected from the three part of the farm were combined to derived one composite sample that represents the whole parcel/farm. Air dry composite soil samples were sieved at 2 mm. Sieved soil samples were analyzed at the Department of Agronomy and Soil Science Laboratory in Leyte State University (LSU) using their standard procedures for the following parameters: pH (water), organic matter (Wackley Balck), total nitrogen (Kjeldahl), extractable-phosphorus (Olsen), exchangeable potassium, soil texture (sand, silt and clay content) and bulk density. Additional details of site characteristics include: GPS location, parcel size, slope details, orientation and soil sampling.

2.4 Definition of site quality indicators

Based on tree data collected from farmers sites an exponential reference growth function was derived for each tree species found:

$$D = a\,e^{bt} \quad (1)$$

Where *a* and *b* factors are determined by logarithmic regression of *D* (Diameter) and *t* (age) for each tree species (Figure 4.1). Thus, trees which are below the reference growth curves grow slower than the average. The delay in performance may be due to many factors (i.e. site conditions, management, germplasm, errors of measurement) but in this analysis only the following site components are quantified: landscape position, soil type, soil physical properties and soil chemical parameters.

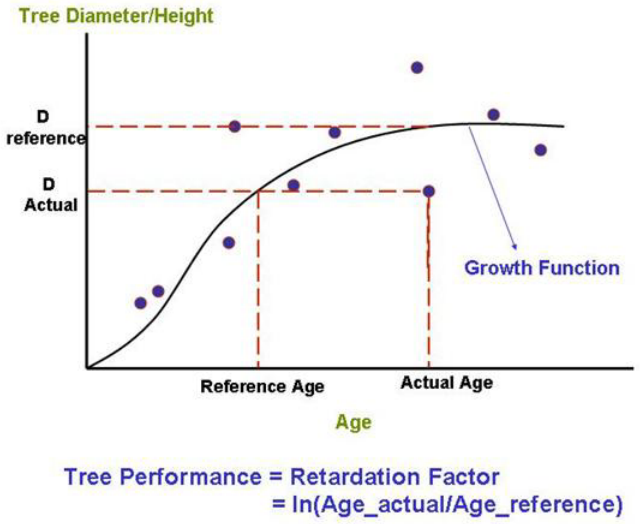

Figure 4.1. Representation of reference growth function and calculation of GRF

Above analysis could be done either by 'relative size per age' (relative to the Y-axis) or by 'relative apparent growth rate' (relative to the X-axis). If the reference growth curve is non-linear (and/or not passing through the origin) these two approaches give different results. Following the methodological approach used by Lusiana and van Noordwijk (2006), it was defined the 'Growth Retardation Factor' (GRF) as the relation between the actual and expected age of one tree given its growth performance. Mathematically is defined as:

$$GRT = \log (t_{observed} / t_{expected}) \quad (2)$$

Where the $t_{expected}$ is calculated as:

$$t_{expected} = (\log (D_{observed}/a))/b \quad (3)$$

with *a* and *b* derived for the total data set for each tree species.

The gain in precision to explain the growth retardation factor as a function of a set of site descriptor was analysed in a step-wise form, increasing its complexity and costs. The first step of the analysis only used site quality information in terms of slope position of introduced trees and its landscape orientation. The second step adds soil map information based on general USDA soil classification. The last two steps, which required more effort and resources, included measured soil properties based on either soil physical (texture and bulk density) properties (step 3) and chemical laboratory analysis (pH, organic mater, N, P, K) in step 4 (Table 4.4).

Table 4.4. Set of site quality indicators used in four (additive) steps of analysis

SITE INDICATOR	PARAMETER	UNIT / CLASSIFICATION
1. Landscape position	Orientation	1-N, 2-NE, 3-E, 4-SE, 5-S, 6-SW, 7-W, 8-NW
	Slope position	1-Summit, 2-Upper, 3-Lower, 4-Bottom
2. Soil Type	Soil class	Based on USDA
3. Soil physical properties	Sand	Content of sand (%)
	Silt	Content of silt (%)
	Bulk density	Bulk density (g/cm^3)
4. Soil chemical properties	pH	Soil pH using 1:1 soil water ratio
	Organic matter	Content organic matter (%)
	Nitrogen	Total N (mg/kg)
	Phosphorus	Extractable-P (me/kg)
	Potassium	Exchangeable-K (me/kg)

The costs of gathering these data are relatively very cheap for the first tow indicators where it is only needed a field technician to measured the site locations using a GPS and later relate that information with available GIS maps. While the last two site indicators (soil physical and chemical properties) are quite expensive because it required detail analysis form a reliable laboratory. Based on the experience from this study it can be approximately estimated the price per sample of 10 (if available maps), 15 and 25 $, respectively. This information will be used to evaluate costs of obtaining various site indicators to the expected gain in predictive power of tree performance.

3. Results

3.1 Planting niches and designs

Four different planting niches were found across the agricultural landscape: in or around annual cropping land, perennial cropping land, grassland and home gardens. Identified farmers´ tree planting designs are as follow: boundary, block, hedgerow-intercropping and scattered (Figure 4.2). Trees found on farmers’ fields were planted in association with other perennial crops (i.e. coconut plantations) or in open grassland areas commonly perceived as fallow lands; while trees intercropped with annual food crops was practiced by few farmers and always in low densities.

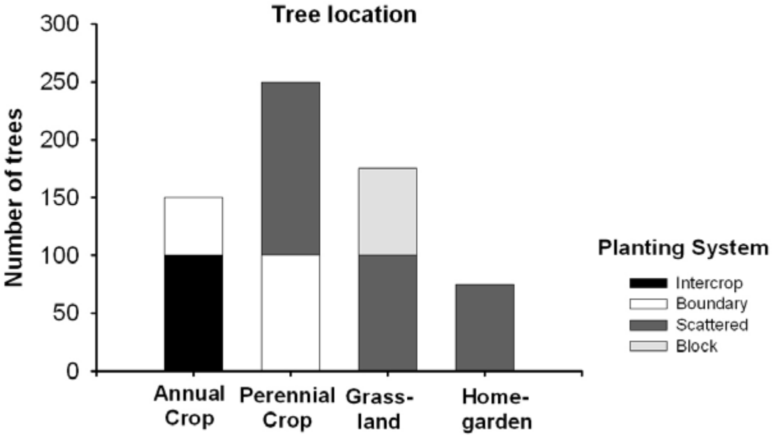

Figure 4.2. Planting niches and designs of native trees found in Manlawaan, Leyte.

3.2 Soil profile

Soils laboratory analysis provided evidence that all sites where trees were found are poor in soil organic matter, total N and extractable P and have a weak soil structure with high silt and low clay content (Table 4.5). Additionally nutrient stocks are already small on calcareous soils and the risk of further soil depletion under annual crop systems is high (PCARRD, 1999).

Table 4.5. Soil physical and chemical analysis from farmers' cooperators sites

Site	pH	OM (%)	Total N (g.kg-1)	Extr-P (me.kg^{-1})	Exch-K (me.kg^{-1})	Bulk density (g.cm^{-3})	Sand (%)	Silt (%)	Soil Class
1	7.9	1.7	0.11	1.9	86.5	1.49	9.6	49.3	Inceptisoil
2	8.0	1.1	0.13	5.1	147.1	1.49	32.6	33.9	Inceptisoil
3	7.8	2.4	0.24	6.0	145.4	1.52	20.6	39.6	Entisoil
4	7.8	2.3	0.27	2.1	59.8	1.71	13.6	39.8	Entisoil
5	7.8	2.2	0.14	6.7	349.0	1.45	19.2	42.2	Inceptisoil
6	7.9	1.8	0.16	1.1	120.6	1.49	9.6	43.3	Inceptisoil
7	7.5	2.7	0.25	2.5	107.7	1.71	9.3	35.2	Entisoil
8	7.9	2.5	0.29	3.3	91.5	1.49	20.0	40.7	Inceptisoil
9	7.5	2.8	0.26	1.3	101.1	1.45	6.9	30.1	Entisoil
10	8.0	1.3	0.11	1.8	95.0	1.71	17.0	35.6	Inceptisoil
11	8.0	2.9	0.23	7.8	167.4	1.49	11.0	35.1	Inceptisoil
12	8.0	2.6	0.26	3.9	63.6	1.45	49.7	28.1	Inceptisoil
13	8.0	1.4	0.16	1.5	68.3	1.71	10.2	41.2	Entisoil
14	8.1	1.2	0.17	2.2	126.0	1.73	10.3	42.2	Inceptisoil
15	7.9	1.7	0.13	2.1	77.8	1.45	6.2	41.6	Entisoil
16	7.9	2.9	0.21	2.4	109.9	1.49	12.7	39.1	Inceptisoil
Mean	**7.9**	**2.1**	**0.13**	**3.2**	**119.8**	**1.55**	**16.2**	**38.6**	**-**
s.d.e.	**0.2**	**0.6**	**0.03**	**2.1**	**68.6**	**0.11**	**11.2**	**5.3**	**-**

3.3 Tree growth performance

Reference growth functions for each species revealed that expected stem diameter reached 30 centimetres between ten and fifteen years of age for all the native trees used (Figure 4.3). This is a reasonable growth rate for medium-term timber trees and very similar to other exotic species as *Swietenia macrophyla* that are widely spread in the Philippines. Substantial variation around this expected growth curve' revealed that the reported age only accounts for 60 to 90% of the observed variation in size, suggesting that trees do differ in their growth performance according to 'site' properties and management factors.

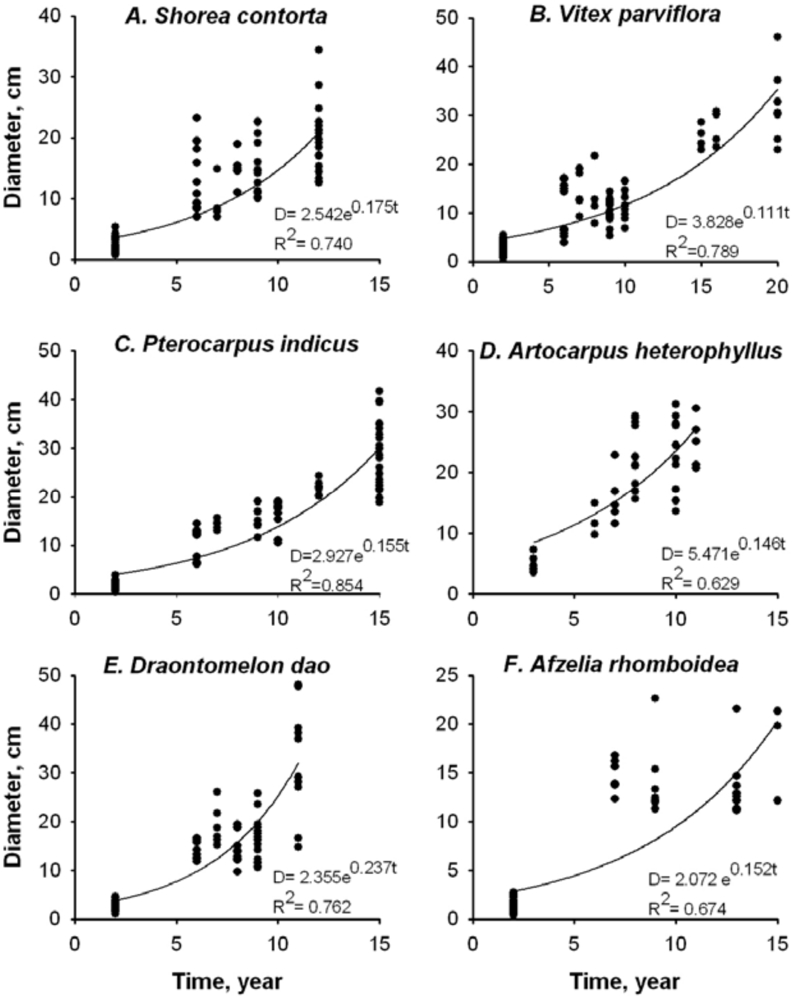

Figure 4.3. Reference growth functions for six native tree species

Based on above growth references functions, the Growth Retardation Factor was calculated for every observed tree (Figure 4.4). Negative values of GRF indicate below-average tree performance. In general, similar symmetrical distributions were found for all age classes, although for bigger trees the distribution for the retardation factor is in general within the range of ±0.5; while for younger trees this range is expand to ±1. This suggests that the growth variation among young trees is much higher than for older ones. This may be linked to lack of precision in recorded tree age, variation in tree size at planting, and or selective survival of only the better performing trees.

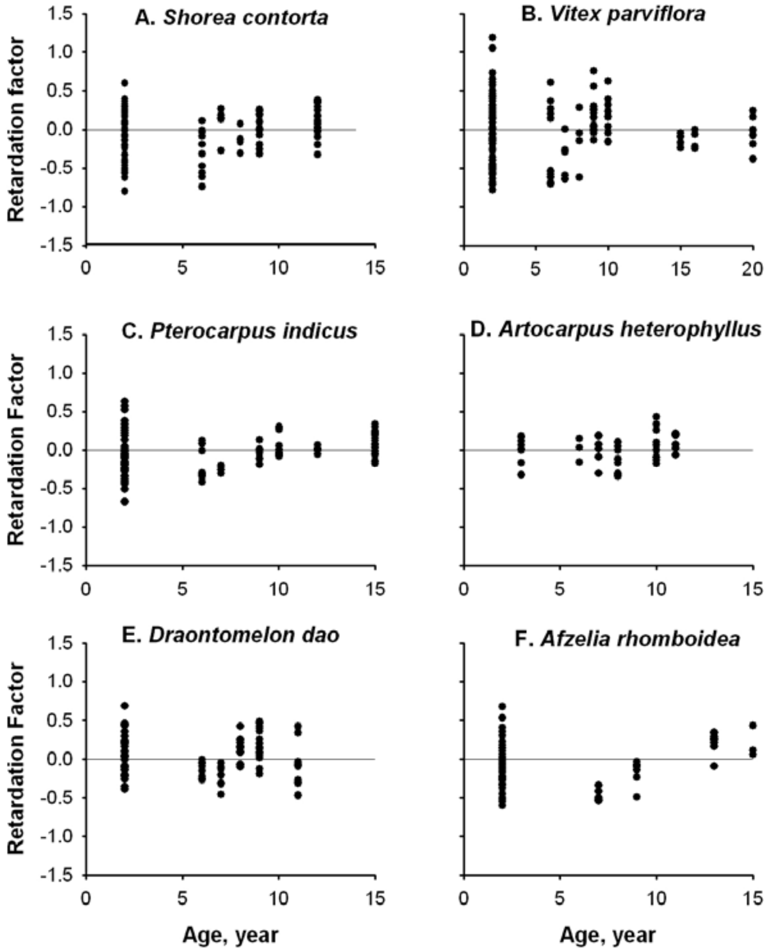

Figure 4.4. Growth Retardation Factor for six native tree species

Stepwise multiple regression analysis was used to account for the variation (adjusted R^2) of the Growth Retardation Factor. Initially each site indicator was included into the model one by one to evaluate the influence of each indicator individually. Afterwards, all possible combinations of site indicators were analyzed together to identify the possible relationships among parameters. A Spearman Rank Order analysis was used for correlation analyses between indicators for which a relationship was apparent by visual inspection of the data.

3.1. Gain in tree-growth prediction in relation to site quality indicators

Overall, regression analysis indicates that selected site quality indicators have different power of prediction explaining tree growth performance depending on the tree species. For instance all possible combinations of site indicators could account for 13-74% of variation in tree performance (Table 4.6). However results clearly shows that landscape position and soil chemical properties stood out as the strongest site indicators explaining tree growth performance for all species. In general, the combination of these two indicators also stood out as the most meaningful arrangement. No significant improvements were found in the gain of power of prediction with the addition of more than two site indicator into the model.

Table 4.6. Step-wise multiple regressions analysis to explain growth performance in relation to site indicators

SITE INDICATORS				**ADJUSTED R^2 (%)**					
Landscape Position	**Soil Type**	**Soil Texture**	**Soil Chemistry**	*S. contorta*	*V. parvifora*	*P. indicus*	*A. Heterophyllus*	*D. dao*	*A. rhomboidea*
X				5.9	1.9	**29.3**	9.7	6.6	**31.3**
	X			3.6	4.7	24.5	9.7	2.7	11.3
		X		9.5	2.3	7.4	46.1	1.5	3.5
			X	**30.5**	**9.7**	6.5	**71.8**	**18.1**	26.4
X	X			9.2	9.5	35.7	23.0	6.0	37.5
X		X		11.7	2.9	36.8	72.7	5.2	35.5
X			X	33.2	**14.0**	**38.0**	**75.0**	**22.3**	**50.0**
	X	X		10.9	5.2	23.8	62.7	9.4	8.5
	X		X	32.0	13.1	24.6	75.7	20.3	33.9
		X	X	**38.6**	8.7	16.4	71.0	20.9	24.6
X	X	X		12.1	9.7	39.4	72.7	4.9	32.7
X	X		X	33.2	**13.8**	37.6	70.0	21.8	44.8
X		X	X	**39.8**	13.3	40.0	**75.6**	**26.3**	**48.0**
	X	X	X	38.7	12.3	**42.1**	75.6	22.9	32.7
X	X	X	X	**39.5**	**12.9**	**39.4**	**74.2**	**25.6**	**50.5**

From the individual soil chemical parameters it was especially significant for *Shorea contorta* and *Draontomelon dao* that contributed to understanding of site quality for this species. For example for *Shorea contorta* the first three site indicators will explain less than 10% of the variation and only when "soil chemistry" is include in the model the gain of explained variation will reach to 40% (Figure 4.5). *Artocarpus heterophyllus* was the species with the highest part of variation accounted for 74.2% and *Vitex parviflora* was the tree specie with the lowest explained variation which only reached 12.9%. The effect of "landscape position" on *Pterocarpus indicus* was very high 29.3% but the rest of site indicators did not add much more information. *Draontomelon dao* also had a low fraction of variation accounted for 25.6% mostly linked to "soil chemical" properties. In summary, these results suggest that some site quality conditions could explain a considerable part of variation in growth performance for some tree species but not for others.

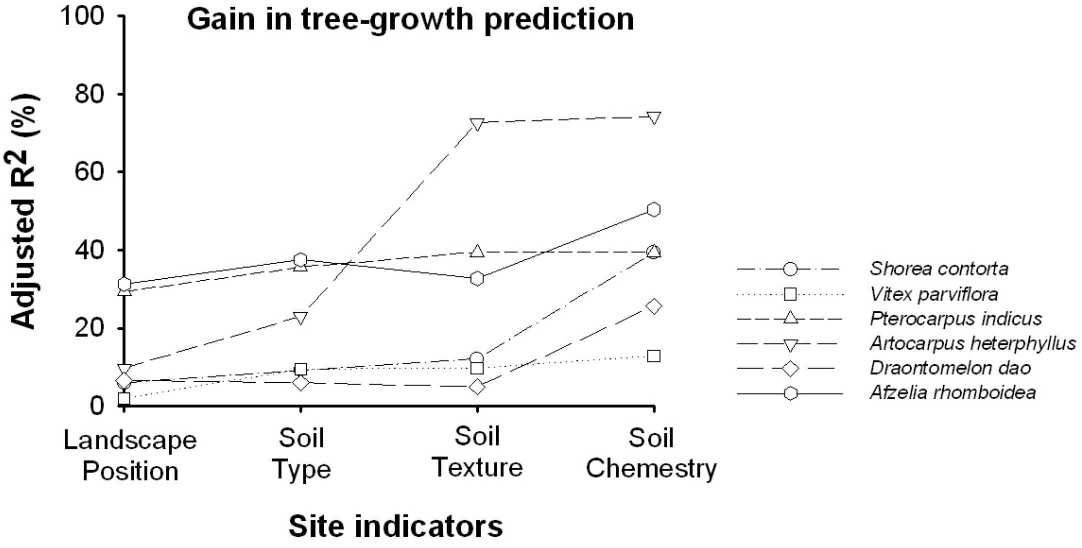

Figure 4.5. Step-wise gain in tree-growth prediction based on a set of simple site indicator

A negative gain in predictive power was registered for *Afzelia rhomboidea* when soil texture was include in the analysis. Correlations among variables need to be taken into account to understand such effects. Results from a Spearman correlation analysis for *Afzelia romboidea* revealed that in fact there is a significant correlation between Bulk Density and Soil Classification (Table 4.7).

Table 4.7. Results from Spearman correlation analysis for *Afzelia romboidea*

	Orienta.	**Slope**	**Soil Class**	**Bulk Density**	**Sand**	**Silt**	**pH**	**OM**	**N**	**P**	**K**
Orienta.	1										
Slope	-0.23	1									
Soil Class	0.42	-0.19	1								
Bulk Density	0.38	-0.44	**0.91**	1							
Sand	-0.31	0.39	-0.42	-0.77	1						
Silt	-0.33	0.04	-0.17	0.19	-0.53	1					
pH	-0.26	0.35	-0.32	-0.12	0.04	0.51	1				
OM	-0.23	0.08	-0.05	-0.08	0.15	-0.27	-0.50	1			
N	-0.08	0.25	-0.08	-0.19	0.26	-0.21	-0.06	0.75	1		
P	-0.15	0.44	-0.19	-0.40	0.54	0.00	0.48	-0.20	0.07	1	
K	0.17	-0.08	0.05	0.30	0.05	-0.06	-0.22	-0.04	0.01	0.36	1

4. Discussion

Agroforestry practices come in many forms but have traditionally been categorized into two groups, those that are sequential, such as fallows, and those that are simultaneous, such as alley cropping (Cooper *et al.*, 1996). However, agroforestry practices should be seen as stages in the development of an agorecosystem such that the increasing interaction of trees into land-use systems can be seen as the passage towards a mature agroforest of increasing ecological integrity (Leakey, 1996). In this way, with increasing scale, the integration of various agroforestry practices into the landscape is like the formation of a complex mosaic of patches in an ecosystem, each of which is composed of many niches. These niches are occupied by different organisms, making the system ecologically stable and biological diverse (Leakey and Simons, 1998). Thus, farmers can start to enrich their agro-ecosystems by progressively integrating trees in their farms resources.

In Leyte, planted trees are becoming increasingly important components of the landscape and land use systems as a strategy to recover degraded areas, maximize land resources and provide higher returns to the farmer (Schulte, 2002). As highlighted on Chapter 3, study results of this section confirmed that many farmers living on already deforested areas and with appropriate land resources spontaneously plant and manage timber trees on farm. A variety of pioneer and premium native species as *Shorea contorta*, *Pterocarpus indica* and *Vitex parviflora* were frequently found on farmers sites in Tabango. This contradicts the common belief among foresters and extensionists in the Philippines (Pasicolan *et al.*, 1997), that farmer are only interested in fast-growing exotic trees. However, the fact that most of the native trees found on farmers´ fields were not planted in association with annual food crops, evidence that farmers are still confronted with the dilemma of whether to integrate or segregate agroforestry systems. Probably, simultaneous agroforestry systems with native trees species are not yet a widely practice among upland farmers in the Philippines because it is not yet demonstrate that it provides a superior land use in terms of feasibility, financial profitability and food security.

The ways and places where farmers plant trees were classified into several major systems, based on the types of land on which introduced trees were found and the planting systems undertaken. These results in defining groups of practices which share important ecological and managerial characteristics are in line with classifications in standard agroforestry text books (Nair, 1993; Young, 1997; Huxley, 1999). Reference growth functions for each native species found, revealed that expected stem diameter reached 20 centimetres between ten and fifteen years of age. This is a reasonable growth rate for medium-term timber trees and very similar to other exotic species as *Swietenia macrophyla* that are widely spread in the Philippines. There is a common belief that farm forestry needs to involve short rotations. For example, according to Macandog *et al.,* (1999), farmers usually harvest short-rotation trees at ages between 4 to 8 years, with a preferred age of 7 years, when trees attain 20 cm dbh or have an average yield of 56 board-feet. The popularity of medium to long-term rotation exotic species, such as Mahogany, demonstrates that farmers are willing to wait longer than what it is commonly assumed if the quality of the final product is higher.

Native trees species commonly are considered by farmers and foresters as slow growing tress, but field observations proved that in fact some of these species grow at least as fast as some exotic. Therefore the domestication of native trees is dealing with an imperfect knowledge base, since these species have often been virtually overlooked by science, and are little known commercially, except in their local area. However, it is now recognized by the scientific community that the bias to native trees improvements needs to be readdressed by the development of novel approaches that take into consideration the requirements of small-scale, resource poor farmers and their farming systems. Given than improvement is as much a social and political challenge as a biological one, it will only be through experimental implementation of a range of approaches that methods and strategies will progress (Leakey and Simons, 1998).

The poor soil conditions encountered in the study area are probably due to inherent soil properties of calcareous soils with low organic matter content, in interaction with the effects of long-term continuous cultivation. In these site conditions, farmers have already started with the integration of trees into their farming systems as a way to improve their resources and conditions. These circumstances thus provide valuable information for assessing the suitability of some commonly used native tree species under different agroforestry systems and soil types.

Regressions analysis results indicates that trees do obviously differ in their growth performance depending on the ‘site’ properties where they are grown but direct relationship between site characteristics and tree growth were difficult to obtain, despite the large variation in the age and growing performance from place to place. Selected site quality indicators have different power of prediction explaining tree growth performance depending on the tree species. However results clearly shows that landscape position and soil chemical properties stood out as the strongest site indicators explaining tree growth performance for all species. Nevertheless, the high variation of tree performance that could not be explained by the biophysical site indicators implicates that farmers take considerable risk in planting trees on the basis of current ‘scientific’ knowledge.

If results are evaluated from a cost-benefit of modified choice based on better (and more expensive) information some suggestions can be made. In general, site quality indicators could only account on average 40% of tree variation and its estimated cost is around 50$ per site sampled. Then, is it really worth it to expend that amount for the expected gain of information? The answer is a clear no from the farmer point of view, and a partial yes from the researcher perspective. The integration of more specific site quality information with the available general spatial information should be the next step of the approach. Despite the low power of tree growth prediction with the selected site quality indicators, the methodology can be considered an important improvement from the past standard GIS procedures which have attend to produce “suitability maps” based on very little information relevant to the particular species´ growth. Probably, the complement of ‘site characteristics’ is ‘management’, and the low determination of tree growth by site properties may in fact be good news for the farmers.

5. Conclusions

- Native tree species found on farmers fields revealed that have a reasonable growth rate for medium-term timber trees and are very similar to other exotic species as *Swietenia macrophyla* that are widely spread in the Philippines.
- Regression analysis results revealed that selected site quality conditions could only account on average 40% of tree growth performance, suggesting that farmers take considerable risk in planting trees on the basis of current ‘scientific’ knowledge.
- Landscape position and soil chemical properties stood out as the strongest site indicators explaining tree growth performance for all species.
- From a cost-benefit point of view results suggests that the approach used is too expensive for individual farmers but offers an important improvement from the past standard GIS procedures.
- Probably, the complement of ‘site characteristics’ is ‘management’, and the low determination of tree growth by site properties may in fact be good news for the farmers.

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5. WHAT SCIENTIFIC INFORMATION EXISTS ABOUT PROMISING NATIVE TREE SPECIES?

Tree database to estimate aboveground biomass

Abstract

Fractal branching models have been expected to provide a 'non-destructive' and generic tool for estimating tree shoot/root length and biomass. The model application to field data has been, however, rarely described in literatures. The WanFBA model was used in this study to estimate above ground tree biomass and tree architecture properties for four promising native tree species based on primary data collection. Reference allometric equations were derived from destructive sampling with the aim to validate and improve the model. Adjustments to the published version of the WanFBA model were made based on the experience after conducting this study, and with the aim to improve the final output. The major change on the model was the addition of a new parameter (tapering coefficientτ) to describe the ratio between up and downstream link diameter. All tests performed confirm the viability of the WanFBA model as a non-destructive tool on predicting above-ground biomass as well as tree components: wood and leaves. Resulted allometric equations have a substantial variation among tree species for the "b" factor around the claims of a universal value of 8/3 and the fact that major parameters, at least in their more extreme values, can be visually recognized should lead to more confidence in the use of the model.

1. Introduction

Lack of scientific information of lesser known tree species, have constrain the utilization and promotion of those species on traditional tree domestication programs. Tree biomass is an essential characteristic that has to be measured for understanding the ecological dynamics related to nutrient cycling, energy flow and ecosystem productivity (Parresol, 1999). Available data that classify trees by their broad climatic requirements and types of use is generally not sufficiently precise to guide local choice, especially for some native tree species in early stages of domestication (Roshetko and Evans, 1999). It is therefore imperative to have appropriate methods and tolls for estimating tree biomass and other important tree properties and parameters (van Noordwijk, 1999).

Tree biomass can be estimated either by destructive or non-destructive methods (Photos 5.1 and 5.2). The destructive methods are laborious and expensive because they involve cutting trees in a specific area, measuring the dry weights of the tree components, and extrapolating the results to larger areas (Araujo *et al.*, 1999). To reduce the need for destructive sampling, biomass can be estimated from an easily measured property such as stem diameter, by using allometric scaling equations (Brown *et al.*, 1995). A substantial number of allometric equations have been developed for trees in various climatic zones, forest types and tree species, using a variety of algebraic forms and parameter values (Ketterings *et al.*, 2001).

Photo 5.1. Above-ground tree biomass measurements through destructive methods

Anybody who wishes to use such equation for a new situation is faced with a difficult choice among the various types of equations. The most commonly used functions are polynomials and power models (van Noordwijk, 1999). Although polynomials (usually quadratic or cubic equations) may provide good fits with the measurement range, their inherent shape is non-natural and extrapolation outside of the range of the original model calibration is risky, (Ketterings *et al.*, 2001). The power function form is widely found within biology (Huxley, 1932) and has some attractive interpretations for scaling. The allometric power equation generally used in estimating aboveground tree biomass is:

$$B = a*D^b \quad (1)$$

where B is biomass (kg) and D is diameter at breast height (cm), and *a* and *b* are parameters that indicate (*a*) tree biomass when the diameter is 1 cm and (*b*) the allometric scaling power. Parameters *a* and *b* can be determined by linear regression of log-transformed B and D (Fownes and Harrington, 1991). It is important, however, to emphasize that these are empirical relationships chosen because they “fit” and that it is not possible for power relationships to hold between the sizes of all plant parts and the total regardless of range of diameter values.

The Functional Branch Analysis (FBA) model was designed by van Noordwijk and Mulia (2002) to generate allometric equations on the basis of easily observed properties of branched systems, in order to allow a more informed choice among empirical equations for specific tree species or even for individual tress in a sampling area. Apart from tree biomass, the model can provide rules for total leaf area; relative allocation of current growth of leaves, branches or stem, 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. For each link a length, volume and number of “end structures” is calculated on the basis of its diameter, and these data are stored in various summation parameters. If such an algorithm for constructing branching patterns is applied many times to trees of different initial diameter, D_o, a range of properties of the tree as whole can be related to D_o, for example by fitting an allometric equation to the data (Mulia *et al.*, 2001).

Fractal branching models make use of self-repeating properties in applying simple rules consistently across a range of scales (van Noordwijk *et al.*, 1994). In trees above as well as below-ground branching follows a simple logic that the amount of transport tissue (functional xylem) where two branches split (or come together, depending on perspective) has to be able to transport the same amount of water before and after the branching point. This consistency leads to a requirement of a near-constant cross-sectional area of xylem (assuming that the maximum size of metaxylem elements is determined by the risk of embolism), and depending on the stem anatomy, to a proportional relation the cross-sectional areas of the whole stem (van Noordwijk, 1999). Any branching point can be described by a transfer coefficient p for the change in total cross-sectional area:

$$p = D^2_{\text{before}} / \sum D^2_{\text{after}} \qquad (2)$$

an other allocation coefficient q for the split of cross-sectional area over the branches:

$$q = \max D^2_{\text{after}} / \sum D^2_{\text{after}} \qquad (3)$$

and one (n) for the number of branches between the axes before and after branching. Direct measurements of diameter change at branching points and statistical analysis to test the independence of these parameters from diameter can establish the viability of the fractal model (van Noordwijk and Mulia, 2002).

Photo 5.2. FBA non-destructive methods to estimate aboveground biomass and tree properties

Precautions are often presented on the use of allometric equations in data sets not similar to the data from which the equations were derived. Biomass of trees varies depending on the site conditions such as soils, vegetation, over storey structure (mean height and diameter) and nutrient impoverishment (Nelson *et al.*, 1999). Ketterings *et al.* (2001) compared the field data collected in a secondary forest in Sumatra with previously published data and found that "*a*" and "*b*" values from the power equation substantially changed. In contrast fractal branching models provide a transparent scheme for deriving tree-specific scaling rules, especially for *b* parameter, on the basis of easily observable, non-destructive methods (van Noordwijk and Mulia, 2002).

Additionally, allometric equations as derived with the WanFBA module can be directly used in the WaNuLCAS model (van Noordwijk and Lusiana, 1999) which is a necessary step to assess possible agroforestry scenarios using less known native tree species. Thus, the overall objective of this study is to develop a tree database that will allow further analysis for selected trees. More specifically this study will (i) develop allometric equations of aboveground biomass for four native species on the basis of parameters that can be measured non-destructively; (ii) test the validity of WanFBA model as a non-destructive tool to estimate biomass and describe tree architecture in terms of branching properties.

2. Materials and Methods

2.1. Tree selection and sample

Four native timber tree species commonly found on farmer's fields planted under different types of agroforestry systems were selected for the study based on farmer's preferences and lack of existing scientific information: *Shorea contorta* Vid. (Dipterocarpaceae), *Vitex parviflora* Juss. (Verbenaceae), *Pterocarpus indicus* Willd. (Fabaceae) and *Artocarphus heterophyllus* Lam. (Moraceae) (ANNEX 3: species description). Four average trees for each species were selected as the sample for destructive and non-destructive measurements of above-ground biomass following the recommendations from van Noordwijk and Mulia (2002).

2.2. Field data collection

Basically WanFBA needs four kind of information to estimate tree biomass as listed in the input sheet: information of tree size, information of branching pattern, information o woody part and information of the final structure of the tree.

2.2.1. Tree size and branching pattern

Field data of diameter and length of links were measured as seen in Figure 5.1. 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 also recorded as follow: the main stem was given link number 1, its offspring are number 2 and 3, and therefore the number of the parent of the main stem is zero (Table 5.1). The number of leaves of each link also recorded. For reliable estimates of the fractal branching parameters, minimum number on 100 branching points were collected for each tree sample as recommended by van Noordwijk and Mulia (2002).

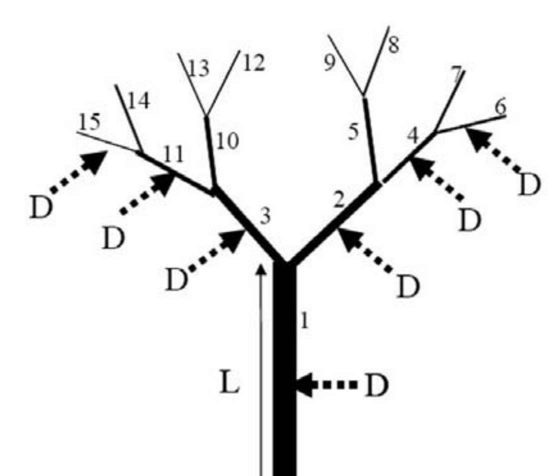

Figure 5.1. Schematic of stem length (L) and diameter (D) measurement

Table 5.1. Data collected to estimate allometric branching part using WanFBA

Branch number	Link to	length	Diameter1	Diameter2	Num. leaves
1	0	L_1	D_{11}	D_{12}	n_1
2	1	L_2	D_{21}	D_{22}	n_2
3	1	L_3	D_{31}	D_{32}	n_3
4	2	L_4	D_{41}	D_{42}	n_4
etc.					

2.2.2. Dry weight estimation

WanFBA classifies the woody part of the tree into three categories: wood, branch and twig. The classification follows the diameter of the link. Twigs were defined for this study as any link with a diameter less than 2 cm; links between 2 and 10 cm were classified as branch, and links above 10 cm diameter as wood.

Dry weight per volume of wood (wood density) was estimated by taking 2 sub-samples (in between 200 to 500 g) of every tree component and determining volume by scale measurements. Sub-samples of all fractions were collected from the field and stored in sealed plastic bags to prevent loss of moisture. Wet weights were recorded immediately upon arrival in the laboratory and dry weighs were determined by drying those samples in an oven at 80ºC until a constant weight has been attained (Padron and Navarro, 2004).

2.2.3. Measure the length of bare tip on final links

Figure 5.2 shows branch having none, medium and long bare tip relatively.

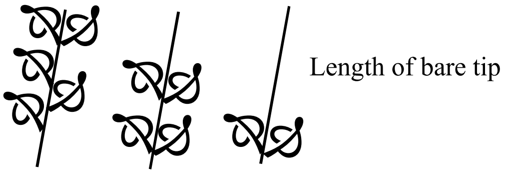

Figure 5.2. Measure the length of bare tip on final links

2.2.4. Measure the final tree structures (leaves)

One hundred leaf samples per tree were collected to determine the average area of a single leaf. Leaf surface area (one side) was measured using WinFOLIA computer software over the scan images of leaf samples. Based on this information Specific Leaf Area (SLA) is defined as the surface area of leaves per unit dry weight (cm^2/g). Dry weight of leaves was determined by drying the samples in an oven at 80ºC during 24 hours.

2.3. Input parameters

The WanFba model automatically processes the field input data and provides a full list of tree parameters as listed below (in italic words are acronyms used in WanFBA):

1. *Nsub:* average number of branching points
2. *p (transfer coefficient*): the ratio between sum of diameter square before branching and sum of diameter square after branching.
3. *q* (*allocation coefficient*): defined as the ratio between the largest diameter square after branching and sum of diameter square after branching
4. *Mean_p:* average of *p*
5. *Mean_q:* average of *q*
6. *STDev_p*: standard deviation of *p*
7. *STDev_q:* standard deviation of *q*
8. *Lbaretip:* length of bare tip on final links

9. *Dmaxfin:* link diameter still having the maximum leaf density and
10. *Dzerofin:* link diameter where leaf density reaches zero
11. *Maxfindens:* number of leaf per centimetre of link before leaf fall has occurred
12. *DwperVwood, DwperVbranch* and *DwperVtwigh:* total dry weight of shoot classified as twig, branch or wood
13. *Tot_Sholength*: total shoot length
14. *Tot_Showeight*: total shoot weight
15. *DW_leaves*: total dry weight of leaves
16. *Leafarea* and *LWR* : total leaf area and Leaf Weight Ratio (relative to total shoot weight)
17. *MinCrownRad* : minimum radius of tree crown
18. *Leaf/(Leaf+twig)* : Leaf weight ratio in twig category
19. *T_BiomDiam1* and *T_BiomDiamSlope* :

    a and b for the equation *Tot_Showeight=a*(Diam_0)^ b*
20. *T_BranchDiam1* and *T_BranchDiamSlope* (above ground system):

    a and b for the equation *DW_Branch=a*(Diam_0)^ b*
21. *T_LeafTwigDiam1* and *T_LeafTwigDiamSlope* :

    a and b for the equation (*DW_leaves+DW_Twig)= a*(Diam_0)^ b*
22. *T_CumLit1* and *T_CumLitSlope* :

    a and b for the equation *Cumulative Litterfall= a*(Diam_0)^ b*
23. *T_CrownRad1* and *T_CrownRadSlope* :

    a and b for the equation *MinCrownRad =a*(Diam_0)^ b*
24. *Ndstep, Linor Log, Ncal* and *Randseed:* These four parameters respectively inform about the number of initial diameter generated, best of fit for logarithmic or linear regression, number of iteration of each parameter combination and the random seed. These parameters are not tree-specific, therefore can be set as default.

2.4. Adjustments to the published version of the model

Based on the experience after conducting this study, a couple of modifications have been made into WanFBA model to improve the final output. In the model, trees are generated by branching-trait parameters (*nsub, p* and *q*) and link length-diameter relationship. For each link length, volume and number of "end structure" is calculated on the basis of its diameter assuming a linear relationship. For the latter, a linear assumption is however not satisfying and was replaced in the model by an averaged link length for each branch category (twig, branch, and wood).

Initially, the model also overestimated the number of links that leads to higher total shoot and leaf biomass. This problem was solved by allowing branches to have a frustum (conical shape) and not always the traditional cylindrical pipe shape. A tapering coefficient τ was introduced to describe the ratio between up and downstream link diameter. Total observed biomass of trees were well predicted with $0<\tau<0.1$. Following the pipe stem theory that a branch section always has $\tau = 0$ (i.e. pipe-shaped) unless self or mechanical pruning has taken place, the difference between total biomass with $\tau = 0$ and $0<\tau<0.1$ reflects potential cumulative litterfall of the observed trees.

2.5. WanFBA validation

Empirical allometric equations derived from destructive methods were used in this study to test the validity of the results from WanFBA. Empirical equations were developed by performing regressions analysis of measured dry weights of cut trees. The regression analysis method involves selecting either randomly or systematically a number of trees (Ola-Adams, 1997; Nelson *et al.*, 1999), in this study trees were selected based on their diameter classes from 2 - 30 cm of dbh. A total number of 10 trees per specie were cut.

Data gathered for destructive method took place in several stages. Each tree was separated in four fractions: leaves, twigs, branches, and all wood rest. Fresh biomass measurements from each fraction were recorded in the field immediately after cutting the tree using a conventional balance. Dry weight per volume of wood (wood density) was estimated by taking 2 sub-samples of every tree component. The coefficient *f* (dimensionless) is the average relation between the dry and fresh weight of each sub-sample for every tree component (Table 5.2).

Table 5.2. Spreadsheet for direct harvest above-ground biomass calculation

Tree Sample #	DBH (cm)	Fresh Weight (kg)	*f* coefficient	Biomass (Kg)
T_1	D_1	FW_{Wood}	f_{Wood}	$f_{Wood}*FW_{Wood}$
		FW_{Branch}	f_{Branch}	$f_{Branch}*FW_{Branch}$
		FW_{Twigs}	f_{Twigs}	$f_{Twigs}*FW_{Twigs}$
		FW_{Leaves}	f_{Leaves}	$f_{Leaves}*FW_{Leaves}$

A linear regression between empirical results (destructive sampling) and predicted estimations (using WanFBA model) was performed to evaluate how close these two observations were to linear relationships. Additional statistics (Loage and Green, 1991) that have been specifically designed for model goodness of fit were also applied (Table 5.3).

Table 5.3. Statistical criteria for model evaluation result according to Loague and Green (1991)

CRITERION	SYMBOL	FORMULA	RANGE	OPTIMUM
Maximum error	ME	$Max\left\|P_i - O_i\right\|_{i=1}^{n}$	≥ 0	0
Root mean square	RMSE	$\left(\sum_{i=1}^{n}\frac{(P_i-O_i)^2}{n}\right)^{\frac{1}{2}} * \frac{100}{O_{mean}}$	≥ 0	0
Coefficient of determination	CD	$\frac{\sum_{i=1}^{n}(Oi-O_{mean})^2}{\sum_{i=1}^{n}(P_i-O_{mean})^2}$	≥ 0	1
Modelling efficiency	EF	$\frac{\left(\sum_{i=1}^{n}(Oi-O_{mean})^2-\sum_{i=1}^{n}(P_i-O_i)^2\right)}{\sum_{i=1}^{n}(Oi-O_{mean})^2}$	≤ 1	1
Coefficient of residual mass	CRM	$\frac{\left(\sum_{i=1}^{n}Oi-\sum_{i=1}^{n}P_i\right)}{\sum_{i=1}^{n}O_i}$	≤ 1	0

Note: P_i = predicted values, O_i = observed values, n = number of samples and O_{mean} is the mean of the observed data.

These statistics are descriptive of the models. EF tells us how well the model is performing in prediction, a value of one indicates a perfect one-to-one relationship and any negative value tells us that the model is worse at predicting observed data than when using the mean of observed values to predict the data. CD is similar to R^2 as it measures the proportion of the total variance of observed data explained by predicted data, a perfect fit also being one with a lower limit of zero and upper limit of infinity. It tells us whether the model is over predicting (a value under one) or under predicting (a value over one). RMSE is the root of the mean square error expressed as a percentage of the observed mean i.e. the average error of predicted results and the ME is the single greatest error between observed and predicted results.

In accordance with Rykiel (1996), for the simulations to be accepted an R^2 value for calibration and validation of 0.9 was considered necessary to indicate a good relationship between predicted and observed values. A CD value between 0.5 and 2 was considered necessary and, although sought, an EF value above zero was not considered necessary as a satisfactory relationship between observed and predicted results does not necessitate absolute predictive accuracy.

3. Results

3.1. Biomass allometric equations

As a result, WanFBA provided final values of tree parameters for each tree species. These parameters are based on average values of a minimum of 400 branching points per species. Table 5.4 show average values of most important branching parameters for each tree species.

Table 5.4. Branching parameters average values by specie using WanFBA model

INPUT PARAMETERS	*Shorea contorta*	*Vitex parviflora*	*Pterocarpus indicus*	*Artocarpus heterophyllu*s	**FBA´s Default**
Nsub	2.14	2.12	2.15	2.07	2.20
Mean_p	1.00	1.05	1.06	1.03	1.00
Mean_q	0.87	0.77	0.80	0.88	0.75
STDev_p	0.19	0.29	0.28	0.24	0.40
STDev_q	0.13	0.16	0.15	0.11	0.30
Lbaretip (cm)	1.00	1.00	1.00	1.00	1.00
Dmaxfin (cm)	1.80	1.80	1.80	1.80	0.80
Dzerofin	2.00	2.00	2.00	2.00	1.60
Maxfindens	0.50	0.40	0.40	0.40	0.40
Average Twig Length (cm)	95.60	95.50	82.30	76.90	-
Average Branch Length (cm)	20.90	72.40	43.00	21.70	-
Average Wood Length (cm)	123.30	172.60	147.20	100.40	-
Average Wood Density (g cm^{-3})	0.48	0.73	0.74	0.45	0.50
Average Branch Density (g cm^{-3})	0.42	0.60	0.61	0.51	0.60
Average Twig Density (g cm^{-3})	0.46	0.81	0.61	0.52	0.70
Specific Leaf Area (m^2 g^{-1})	50.20	34.90	369.70	32.20	95.00
Average leaf area (cm^2)	71.00	116.90	265.80	55.20	50.00
Leaf Area Index (dimensionless)	6.03	1.09	6.27	2.55	3.00

Nsub= average number of branching points; *p*=transfer coefficient; *q*= allocation coefficient; *Mean_p*=average of *p*; *Mean_q*=average of *q*; *STDev_p*= standard deviation of *p* values; *STDev_q*= standard deviation of *q* values; *Lbaretip* = length of bare tip on final links; *Dmaxfin*= diameter of a link when leaf density maximum; *Dzerofin*= diameter of a link when leaf density zero *Maxfindens*= number of leaves per centimetre of links;

The final output of WanFBA model is the allometric equations for the total above ground tree biomass as well as for each of the tree components: wood and leaves. As it can be seen on Table 5.5, resulted allometric equations have a substantial variation among tree species for "*b*" factor around the claims of a universal value of 8/3.

Table 5.5. WanFBA allometric equations ($Y = aD^b$) for total aboveground biomass and tree components: Wood and Leaves

ALLOMETRIC EQUATIONS	*Shorea Contorta*	*Vitex parviflora*	*Pterocarpus indicus*	*Artocarphus heterophyllus*
(a) factor for Total_Biom	0.035	0.133	0.063	0.065
(b) factor for Total_Biom	2.870	2.360	2.540	2.282
(a) factor for Wood_Biom	0.007	0.046	0.025	0.018
(b) factor for Wood_Biom	3.326	2.679	2.819	1.671
(a) factor for Leaf_Biom	0.055	0.179	0.084	0.110
(b) factor for Leaf_Biom	2.224	1.582	1.721	1.440

To complete the outputs, WanFba gives a graph that shows relation between the biomass and the initial diameter (Figure 5.3). As these graphs were built in log-log scale, straight lines on log-log plot of stem diameter against tree biomass, confirm the validity of allometric power equations within the relations used in the model.

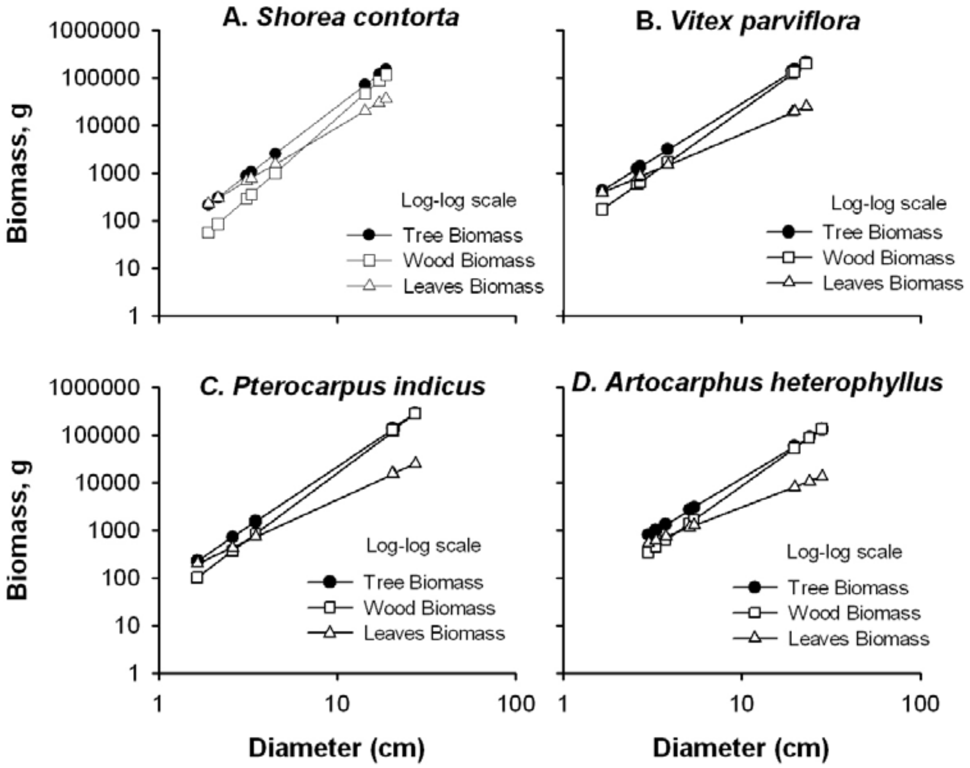

Figure 5.3. WanFba output: relation between tree biomass and initial diameter

3.2. WanFBA validation results

Total above-ground tree biomass as calculated with the allometric equations from WanFBA model, fit well with the biomass measurements obtained from destructive methods (Figure 5.4.A). Slight differences were found for tree components: wood (Figure 5.4.B) and leaves biomass (Figure 5.4.C) for all four tree spices.

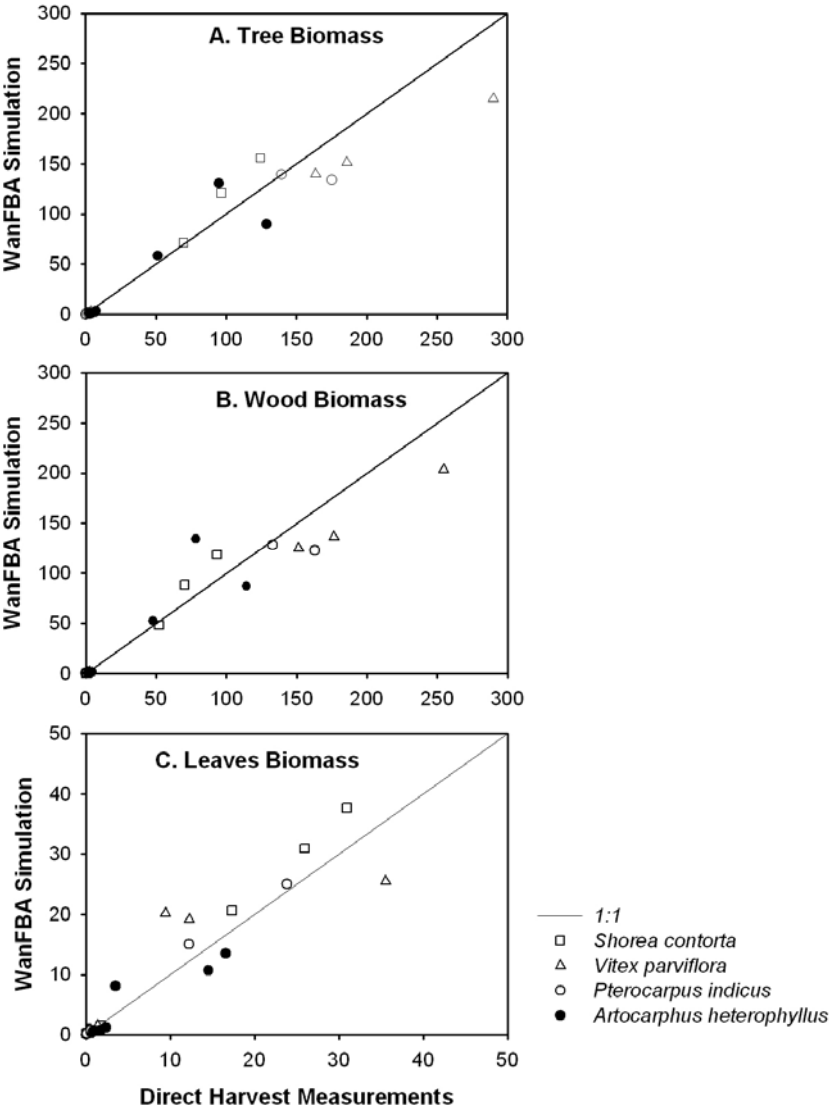

Figure 5.4. Comparison of WanFBA and Direct harvest biomass values for all tree species: A. Tree Biomass (kg), B. Wood Biomass (kg) and C. Leaves Biomass (kg).

Statistical test analysis also confirmed the viability of the WanFBA model for all tree species. Indeed, all test performed on WanFBA results indicated that the model is applicable and provides an acceptable approximation for total aboveground biomass estimation as well as for the tree components (wood and leaf) (Table 5.6). The largest discrepancies were found for *Vitex parviflora* and *Pterocarpus indicus,* probably because for these two species trees of larger stem diameter were included in the measurements than for *Shorea contorta* and *Arthocarpus heterophyllus*.

Table 5.6. Statistical validation of WanFBA model for above-ground biomass estimation according to Loague and Green (1991)

TREE SPECIES	**TREE**	**WOOD**	**LEAVES**
Shorea contorta			
R^2	0.96	0.94	0.96
ME (0, ≥ 0)	19.52	27.19	66.48
RMSE (0, ≥ 0)	21.04	51.30	331.29
EF (1, ≤ 1)	0.95	0.69	-11.87
CRM (0, ≤ 1)	-0.07	0.45	-2.55
CD (1, ≥ 0)	0.86	0.73	0.96
Vitex parviflora			
R^2	0.971	0.985	0.925
ME (0, ≥ 0)	41.61	112.15	107.78
RMSE (0, ≥ 0)	22.63	61.33	505.91
EF (1, ≤ 1)	0.95	0.67	-24.25
CRM (0, ≤ 1)	-0.03	0.46	-3.55
CD (1, ≥ 0)	0.88	0.87	0.93
Pterocarpus indicus			
R^2	0.97	0.95	0.97
ME (0, ≥ 0)	45.63	80.59	103.15
RMSE (0, ≥ 0)	31.56	64.21	580.13
EF (1, ≤ 1)	0.92	0.67	-26.53
CRM (0, ≤ 1)	-0.06	0.46	-3.68
CD (1, ≥ 0)	0.99	0.98	1.00
Artocarphus heterophyllus			
R^2	0.98	0.99	0.81
ME (0, ≥ 0)	21.97	43.00	49.16
RMSE (0, ≥ 0)	22.60	61.63	527.75
EF (1, ≤ 1)	0.97	0.76	-7.61
CRM (0, ≤ 1)	-0.13	0.41	-4.03
For all species			
R^2	0.97	0.96	0.90
ME (0, ≥ 0)	45.63	112.15	107.78
RMSE (0, ≥ 0)	27.27	66.76	495.40
EF (1, ≤ 1)	0.95	0.71	-19.27
CRM (0, ≤ 1)	-0.06	0.45	-3.33
CD (1, ≥ 0)	0.90	0.88	1.02
CD (1, ≥ 0)	0.79	0.79	1.41

ME: maximum error, RMSE: root mean square error, EF: model efficiency, CRM: coefficient of residual mass, CD: coefficient of determination.

4. Discussion

Fractal branching models have been expected to provide a ‘non-destructive’ and generic tool for estimating tree shoot/root length and biomass. Application of the model to field data has been, however, rarely described in literature. Through this study, application of the WanFBA fractal branching model for estimating shoot, and leaf biomass was validated for four native tree species, in which scientific information as such was lacking before.

Experience with the WanFBA from this study shows that the transfer coefficient (*p)* and branch allocation coefficient (*q*), which links relation between diameter and link length has the strongest influence on the final allometric equation especially on the *b* factor. It is suggested that before use the WanFba program, users should check the relation between mean_p and mean_q with the parent diameter. Users can use the output of inputfba program which lists the mean_p and mean_q values with the associated parent diameters, and test the relation using regression technique. Only if the relation (can be indicated by r2) is relatively independent that the fractal branching approach used in WanFba is useful to estimate the tree biomass.

The parameters of the branching process are characteristics of tree species, and thus can be meaningfully entered in databases. As mention by Mulia *et al.* (2001), the fact that the major parameters (at least in their more extreme values), can be visually recognized should lead to more confidence in the use of the method. With the purpose to visually validate outputs from the model, WanFBA model included an additional tool to visualize tree branch data (3D Virtual Branch 1.0.3). Figure 5.5. shows visualisation results of tree shapes and branching pattern for all four tree species, and its relation with WanFBA estimated allometric equation (b factor).

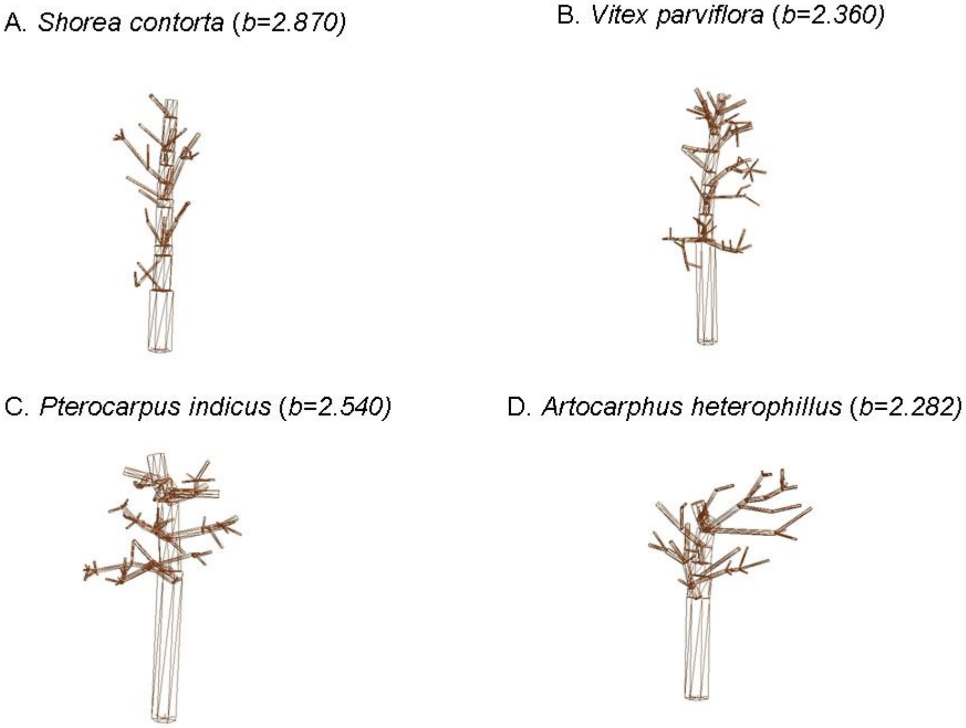

Figure 5.5. Visualization of tree branch data using 3D Virtual Branch 1.0.3.

Although the 8/3 for allometric scaling of trees has a biomechanical interpretation that may appear to be generic (West *et al.*, 1999), results from this study suggest that scaling rules in the range 2.3-2.9 are consistent with tree shapes and branching pattern for individual tree species. Thus, the fractal branching analysis offers promise for a better understanding of why, when and how to modify allometric scaling relations form the generic "default" values recommended in the forestry literature (van Noordwijk, 1999).

Implementing WanFBA software to predict tree biomass (only above-ground), is proven from this study to be easier and cheaper than destructive methods. However, comparisons results between these two methods made possible the validation and improvement of the model. Adjustments to the published version of the WanFBA model were made based on the experience after conducting this study, and with the aim to improve the final output. The major change on the model was the addition of a new parameter (tapering coefficientτ) to describe the ratio between up and downstream link diameter. The latter were calculated to be around 8-10 times to the current leaf+twig biomass. Although results form this study justify the inclusion of a tapering coefficient into the model further studies and field data are still needed.

Applicability of WanFBA outputs depends on whether or not the assumptions underlying the fractal (scale-independent) process are meet in the real world. The basic assumptions have been tested and found to be applicable as acceptable first approximation for a wide of tropical trees, although a number of extensions of the theory have been suggested for various situations (Pages *et al.*, 2000; Ozier-Lafontaine *et al.*, 1999; Rowe, 1999; Smith, 2001). Actually WanFba is simplification of FBA (Functional Branch Analysis) program which is also made in excel. The true FBA contains more complex approaches especially in estimating the below ground biomass. WanFba was made especially because the allometric scaling relations as derived from WanFBA model can be directly used in the WaNuLCAS model (van Noordwijk *et al.*, 2004), which will allow assessing possible agroforestry scenarios utilizing new tree species included on its tree library.

5. Conclusions

- All tests performed confirm the viability of the WanFBA model as a non-destructive tool on predicting above-ground biomass as well as tree components (wood and leaves).
- Implementing WanFBA software to predict tree biomass (especially above-ground), is proven from this study to be easier and cheaper than destructive methods.
- The fact that the major parameters (at least in their more extreme values), can be visually recognized should lead to more confidence in the use of the method.
- Adjustments to the published version of the WanFBA model were made based on the experience after conducting this study, and with the aim to improve the final output.
- The allometric scaling relations as derived with the WanFBA module can be directly used in other agroforestry models which will allow further analysis.

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6. WHAT ARE POSSIBLE AGROFORESTRY SCENARIOS USING NATIVE TIMBER TREES?

Model simulation to quantify trade-offs between trees and crops from a wide array of possible management options

Abstract

To assess possible agroforestry scenarios the tree-soil-crop interaction model in agroforestry systems (WaNuLCAS 3.1) was used based on-site specific data collected from Tabango (Central Philippines). Three native timber trees (*Shorea contorta* Vid., *Pterocarpus indicus* Juss., and *Vitex parviflora* Willd.) and one widely spread exotic specie (*Swietenia macrophylla* King.*)* were simulated under different intercrop scenarios with maize (*Zea mays* L.) and subsequently compared. Model simulation results quantified and explained trade-off between tree and crop. For example, higher tree densities will lead to a loss of crop yield that is approximately proportional to the gain in wood volume. However, beside this trade-off effect, there is considerable scope for tree intercropping advantage under a fertilization scenario, with systems that yield about half of the maximum tree biomass still allowing 70% of monoculture maize yield. Maximum tree yield can still be obtained at about 20% of the potential crop yield but intermediate tree population densities (400 trees/ha) and the resulting larger stem diameters may be preferable over the larger total tree biomass obtained at higher tree densities. Another advantage from intercropping systems is that trees directly benefit from the inputs (i.e. fertilizer) that are applied to the crops. The three native trees species studied have different performance in relation to productivity but are similar to (or even better than) *S. macrophylla*. As a result, *P. indicus* and *V. parviflora* stood out as promising “agroforestry" native trees at intermediate densities. By contrast, in a non fertilization scenario the rapid decline in crop yields meant that agroforestry options are not better than tree monoculture, regardless of the tree species and spacing selected.

1. Introduction

On degraded land it is hard to maintain a farming lifestyle based on annual food crops alone (Ong *et al*., 1996). Farmers struggle to overcome agricultural constraints to maintain production, or adapt their choice of crops to the conditions of a place i.e. farmers switch from maize to cassava when soils become degraded (Agpaoa *et al*., 1976) (Photo 6.1). Later on, farmers may raise productivity and income by planting trees on excess land that cannot be put under annual crops (Ahmed, 1989). Another alternative will be to plant trees and crops simultaneously. Intercropping systems are often cited as an effective and efficient strategy for two reasons: (i) the intensive land preparation for crops ensures tree survival and promotes growth; and (ii) the costs of tree establishment and management can be charged to the intercrop (Garrity, 1997; Bertomeu, 2004).

Photo 6.1. Soil erosion process on abandon sloping degraded areas form the study site

According to Young (1997) trees introduced into annual cropping systems help to overcoming degraded soil conditions by (a) providing a slowly decomposing litter layer that protects the soil from splash impacts of rainfall, reduces runoff and maximise water and nutrient resource use, (b) adding substantial amounts of organic matter through litter layer and root turnover, allowing for a gradual recovery of soil structure; and (c) capturing nutrients from deeper soil layers or intercepting current leaching losses, depending on their root distribution. However, trees have to represent direct as well as indirect economic value, to offset their resource capture in competition with annual crops (Huxley, 1999). Nowadays, many smallholders are willing to plant high quality timber trees even if rotations are longer, because of their compatibility with associated crops and the higher market price of quality products (Shulte, 2002). *Swietenia macrophylla* (Mahogany) is a good example of well promoted good quality exotic timber tree, while there is a vast number of native timber species with high market potential that have not yet been explored.

In simultaneous agroforestry systems, trees and food crops are interacting in various ways. The key for the success of agroforestry practices strongly depends on how well the advantageous effects are maximized and the disadvantageous effects minimized (Nair, 1993). As cited by van Noordwijk *et al.* (2004a) the most important interactions in intercropping systems are: (1) Shading by the trees, reducing light intensity at the crop level; (2) Competition between tree and crop roots for water and nutrients in the topsoil; (3) Mulch production for the tree, increasing the supply of N and other nutrients to the food crops; (4) Nitrogen supply by the tree roots to crop roots, either due root death or by direct transfer if nodulated roots are in close contact with crop roots; (5) Effects on weeds, pests and diseases; (6) Long term effects on erosion, soil organic matter content and soil compaction. As both positive and negative interactions occur, optimization of the system will have to be site specific.

Even though farmers can instinctively anticipate crop yield losses as trees grow, they would likely be unable to accurately predict the period of viable intercropping and the net profit over the tree rotation. Thus, during a farm planning period farmers will have to make decisions at a number of levels. Some decisions refer to the field scale on a multiyear basis (strategic choices of tree species and spacing), others to annual decisions at field scale (tactical decisions on cropping pattern and fertilization), a third group to household and landscape scale considerations that involve the tradeoffs between productivity and environmental service provision at field scale, and the best use of household level resources of land and labour (van Noordwijk *et al.*, 2004b). Most, if not all, of these decisions are beyond the reach of a purely empirical approach, as the number of options is too vast. The use of existing simulation agroforestry models as WaNuLCAS 3.01 (van Noordwijk and Lusiana, 1999) to explore a broad range of options and zoom in on the combinations that are most likely to meet farmers' expectations comes as a logical alternative.

WaNulCAS 3.01 (Water, Nutrient and Light Capture in Agroforestry Systems) is a model of tree-crop interaction in agroforestry system. The model is formulated in the STELLA research modelling environment. An up-to-date free version of WaNulCAS model can be obtained from www.icraf.org/sea/AgroModels/WaNulCAS/index.htm. The key feature of the model is the description of uptake of water and nutrients on the basis of root length densities of both the tree and the crop, plant demand factors and effective supply by diffusion at a given soil water content (van Noordwijk *et al.*, 2004b).

The model represents a four-layer soil profile (vertical), with four spatial zones (horizontal), a water and nitrogen balance and uptake by a crop and a tree (Figure 6.1). The user can define the width and depth of each zone and adjust it to the type of system simulated. The model can be used both for simultaneous and sequential agroforestry systems and may help to understand the continuum of options ranging from improved fallow via relay planting of tree fallow to rotational and simultaneous forms of hedgerow intercropping. The model explicitly incorporates management options such as tree spacing, choice of species and pruning regime. The model includes various tree characteristics, such as (dynamic) root distribution (over the 16 cells; four layers * four zones), canopy shape (above the four spatial zones), litter quality and maximum growth rate. If applied to hedgerow intercropping, the model allows for the evaluation of crop growth at different tree spacing, densities or fertilizer application rates (van Noordwijk and Lusiana, 1999).

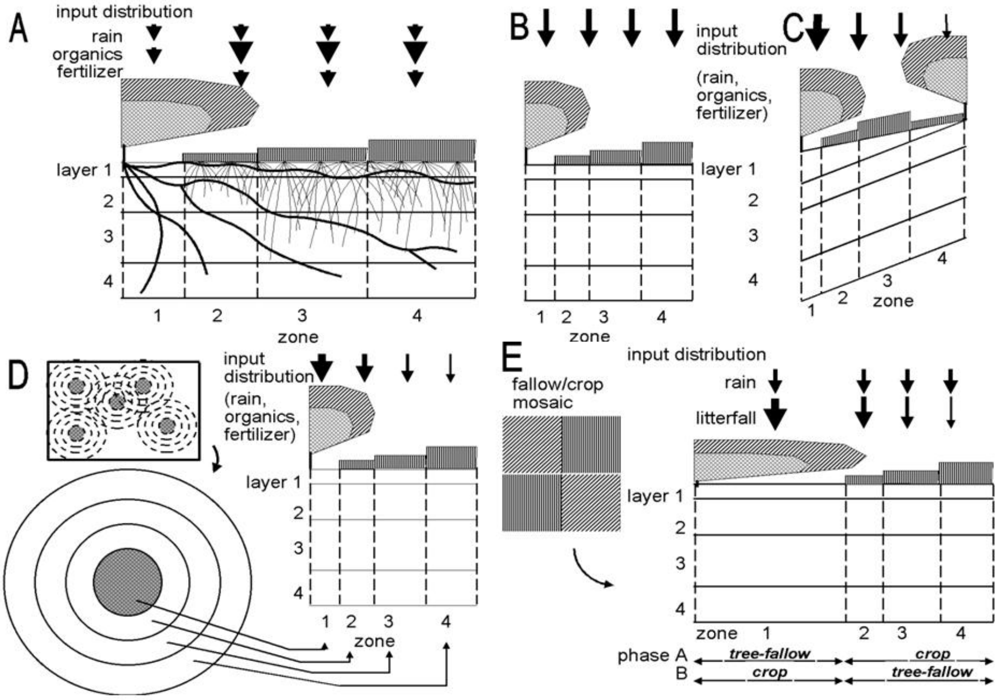

Figure 6.1. General layout of zones and layers in the WaNuLCAS model (A) and applications to four types of agroforestry systems; (B) Alley cropping; (C) Contour hedgerows on slopes, with variable topsoil depth; (D) Parkland systems, with a circular geometry around individual trees; (E) Fallow-crop mosaics with border effects. (Source: van Noordwijk and Lusiana, 1999)

A number of inputs to the soil surface can be distribute proportional to the relative surface areas or heterogeneously. In this way, we can for example account for surface runoff of rainfall in one zone and its infiltration in another. Separately, patch-level net run-on or run-off can be implemented.

Similar weighting factors are used for allocating litterfall, tree pruning, fertilisers and crop residues to the various zones, while conserving their overall mass balance (van Noordwijk *et al.*, 2004b).

Climate effects are mainly included via daily rainfall data, which can be either read from a spreadsheet or generated on the basis of a daily probability of rainfall and an expected monthly rainfall total. The water balance of the system includes rainfall, with the option of exchange between the tree zones by run-on and run-off, surface evaporation, uptake by the crop and tree and leaching. For the description of the soil water balance in soil plant models a number of processes should be combined which act on different time scales (van Noordwijk and Lusiana, 1999).

Soils are represented in four layers, the depth of which can be chosen, with specified soil physical properties and initial water and nitrogen contents, for all sixteen cells (van Noordwijk *et al.*, 2004b). The model needs the relationship between water potential and soil water content, to derive the soil water content equivalent to certain root water potential (van Genuchten, 1980). As the relationships are not measured for all soils, pedotransfer functions are used (Arah and Hodnett, 1997). Soil physical parameters included into the model are derived via a pedotransfer function from soil texture, bulk density and soil organic matter content from field data (Suprayago *et al.*, 2003). WaNuLCAS pedotransfer functions for hydraulic properties of soils are adapted for Wosten *et al.* (1998).

The nitrogen balance of the model includes inputs from fertilizer (specified by amount and time of application), atmospheric N fixation and mineralization of soil organic matter and fresh residues (van Noordwijk and Lusiana, 1999). Uptake by crop and tree is allocated over yields and recycled residues. Leaching of mineral N (nitrate) is driven by the water balance, the N concentrations and apparent adsorption constant for nitrate in each layer. Decomposition of soil organic matter is represented by a three-pool model, following the terminology and concepts of the Century model (Parton *et al.*, 1994).

Growth of both plants (crop and tree) is calculated on a daily basis by multiplying potential growth (which depends on climate and current plant size) with the minimum of four stress factors: one for shading, one for water limitation, one for nitrogen and one for stress history. Uptake, U, of both water and nutrients by the tree and crops is driven by demand, D, but within limits set by a zero-sink uptake model (de Willigen and van Noordwijk, 1994). Competition is based on sharing the potential uptake rate for both (based on the combined root length densities) on the basis of relative root length multiplied by relative demand (van Noordwijk *et al.*, 2004b).

Therefore, WaNulCAS model was selected for this study mainly with two objectives: (1) to evaluate biophysical feasibility and sustainability for different land use systems (2) to assess the trade-offs between native trees and crops from a wide array of possible agroforestry scenarios.

2. Materials and Methods

2.1. WaNulCAS requirements before simulations

To be able to run and produce a “simple regular”[8] output WaNulCAS needs a minimum set of input parameters named Core Module (ANNEX 4). Core module set of input parameter include:

- Climate conditions: rainfall, temperature
- Soil profile: slope, texture, organic mater, bulk density, nutrients (nitrogen or phosphorus)
- Tree functional parameters: biomass equation, phenology, canopy and support structure
- Crop functional parameters: potential growth rates and allocation to harvested organs
- Management options: tree species and spacing, crop types and planting schedules, trees and crops harvest events, use of fertilizer and / or organic inputs (i.e. crop residues)

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[8] By “simple regular” means, no outputs produced from specific module (i.e. slash & burn or pest & diseases)

Additionally, before site specific field measurements / observations become input parameters of core module need previous process as required by WaNuLCAS (van Noordwijk *et al.*, 2004b). A model validation test for final input parameters is required before running selected simulations scenarios. Particularly for this study, as tree species simulated were not taken from WaNulCAS tree-database, tree parameters had to pass by specific validation process before being accepted.

2.2. Tree growth validation test

Before start running selected simulation scenarios it was necessary to calibrate tree parameters to validate predicted tree growth performance by WaNuLCAS. Each tree species was run for ten year period in a tree monoculture simulation and predicted results were compared with empirical field measurements. Linear regression between empirical tree growth (field measurements) and predicted output (using WaNuLCAS model) was performed to evaluate how close model results fit to linear relationships. Additional statistics (Loage and Green, 1991) that have been specifically designed for model goodness of fit were also applied (Table 6.1).

Table 6.1. Statistical criteria for model evaluation result according to Loague and Green (1991)

CRITERION	SYMBOL	FORMULA	RANGE	OPTIMUM
Maximum error	ME	$Max\left\|P_i - O_i\right\|_{i=1}^{n}$	≥ 0	0
Root mean square	RMSE	$\left(\sum_{i=1}^{n}\frac{(P_i - O_i)^2}{n}\right)^{\frac{1}{2}} * \frac{100}{O_{mean}}$	≥ 0	0
Coefficient of determination	CD	$\frac{\sum_{i=1}^{n}(Oi - O_{mean})^2}{\sum_{i=1}^{n}(P_i - O_{mean})^2}$	≥ 0	1
Modeling efficiency	EF	$\frac{\left(\sum_{i=1}^{n}(Oi - O_{mean})^2 - \sum_{i=1}^{n}(P_i - O_i)^2\right)}{\sum_{i=1}^{n}(Oi - O_{mean})^2}$	≤ 1	1
Coefficient of residual mass	CRM	$\frac{\left(\sum_{i=1}^{n}Oi - \sum_{i=1}^{n}P_i\right)}{\sum_{i=1}^{n}O_i}$	≤ 1	0

P_i = predicted values, O_i = observed values, n = number of samples and O_{mean} is the mean of the observed data

In accordance with Rykiel (1996), for the simulations to be accepted an R^2 value for calibration and validation of 0.9 was considered necessary to indicate a good predicted to observed relationship. A CD value between 0.5 and 2 was considered necessary and, although sought, an EF value above zero was not considered necessary as a satisfactory relationship between observed and predicted results does not necessitate absolute predictive accuracy.

2.3. WaNuLCAS core module: set of input parameters

2.3.1. *Climate conditions*

Daily rainfall data were collected during year 2004 from Manlawaan, municipality of Tabango ICRAF-Visayas research site. Annual average rainfall is 2200 mm with a monthly distribution that clearly identifies a wet (June to December) and dry (January to May) season (Figure 6.2). As cited by Groestschel (2001) Leyte is a typhoon prone area, with one month during wet season which is above rainfall average and were the risk of landslide and flood[9] is very high. Model default air and soil temperature were used for the simulation due a lack of data in this respect.

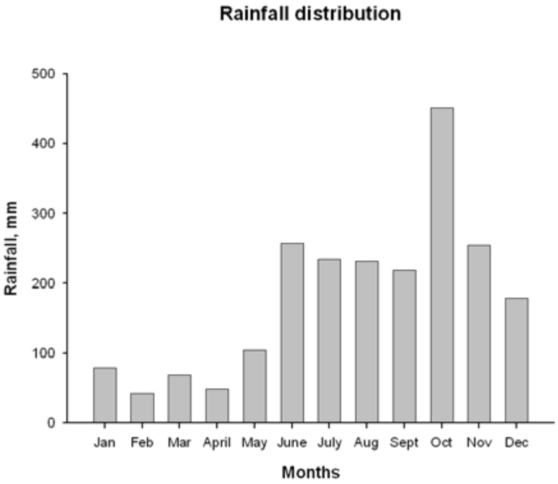

Figure 6.2. Monthly rainfall distribution in Tabango, Leyte (Source: Daily field measurements provided by ICRAF-Visayas Research site in 2004)

2.3.2. *Soil profile*

The study site is located in a sloping area environment with an average of 20% slope. Soil physical and chemical properties were based on a catena study conducted in the Municipality of Tabango by the Department of Agronomy and Soil Science, College of Agriculture, Leyte State University (Gemao *et al.*, 2003). Characterization of soils was based on four soil profiles across the landscape catena: summit, upper-slope, lower-slope and button-slope (Photo 6.2).

Soil is represented in the model in four layers, the depth of which was chosen based on average values. Soil physical and chemical characteristics, were derived via WaNuLCAS pedotransfer functions from soil texture, bulk density and soil organic matter content from field data (Table 6.2). The nutrient balance of the model includes inputs from fertilizer (specified by amount and time of application), atmospheric N fixation a mineralization of soil organic matter and fresh residues.

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[9] Every year Leyte is hit by dangerous typhoons creating important landslide and floods. In the year 2005 more than a thousand people died when a landslide buried Guinsaugon village.

Table 6.2. Soil physical and chemical characteristics of the study site included in WaNuLCAS core module

Soil Depth	**Clay**	**Silt**	**Organic Matter**	**Bulk Density**	**P_{Olsen}**	**Soil Texture**
cm	%	%	%	g cm^{-3}	mg cm^{-3}	
0 – 10	21.4	60.9	2.68	1.387	10.52	Light clay
10 – 40	21.6	59.8	1.43	1.429	7.90	Light clay
40 – 60	24.0	57.6	1.10	1.423	8.26	Light clay
60 – 100	22.2	58.9	0.99	1.442	8.12	Light clay

2.3.3. *Tree functional parameters*

Aboveground biomass allometric equations as derived form the WanFBA module (van Noordwijk and Mulia, 2002) were included into the set of input parameters for *Shorea contorta* Vid., *Pterocarpus indicus* Juss., and *Vitex parviflora* Willd. (Table 6.3). These functions were developed and validated based on primary field data measurements. Other required tree functional parameters included into the model based on field measurements are: specific leaf area (SLA), leave area index (LAI), canopy diameter and shape. Parameters such as maximum growth rate, maximum daily mobilizable fraction of growth reserves or cumulative literfall equations were calibrated by fitting predicted to observed relative biomass functions (Mulia *et al*., 2001). Belowground parameters, as root type and biomass were taken from default values coming from WaNuLCAS tree library.

Table 6.3. Aboveground biomass allometric equations ($Y = aD^b$) to simulate tree growth in WaNuLCAS

ALLOMETRIC EQUATIONS	*S. contorta*	*V. parviflora*	*P. indicus*
(a) factor for Total_Biom	0.084	0.118	0.177
(b) factor for Total_Biom	2.548	2.493	2.440
(a) factor for Wood_Biom	0.036	0.025	0.031
(b) factor for Wood_Biom	2.794	3.074	2.968
(a) factor for Leaf_Biom	0.120	0.015	0.011
(b) factor for Leaf_Biom	1.928	2.466	2.340
(a) factor for Cumulative_Literfall	0.014	0.004	0.004
(a) factor for Cumulative_Literfall	3.094	3.094	3.094

One more tree specie *Swietenia macrophylla* King. (Mahogany) was included in the study as the tree growth reference. Mahogany was selected because is an exotic timber tree vastly introduce in the Philippines and has similar characteristics than the three native trees selected for this study. Tree functional parameters for Mahogany were taken for WaNuLCAS tree library.

2.3.4. *Crop selection*

Maize (*Zea mays* L.) was selected as the crop for the intercrop scenarios because is the most preferred food crop among upland farmers in the study site (Groestschel, et al., 2001). Two cropping seasons per year were set for the model simulation according farmers practices based on field observations. No changes were made in the default parameters for Maize (*Zea mays* L.) from WaNuLCAS crop library.

2.3.5. Management options

WaNuLCAS was used to provide simulations scenarios of a wide array of realistic management options that make a transition from crop monoculture towards tree-dominated systems. Thus, three possible land uses scenarios were characterized and simulated into the model for comparison purposes: (i) maize monocropping, (ii) hedgerow tree intercropping and (iii) tree monoculture.

All three scenarios were run with WaNuLCAS for a period of 15 years (30 cropping seasons). A simulation period of 15 years was considered because this is the normal tree rotation for medium-term species (Valdez, 1991). For maize monocropping and tree intercropping systems simulations outputs were compare with and without the utilization of fertilizer. For those systems under a fertilization conditions, N and P were applied only to the crop at an amount of 45 kg N ha^{-1} and 30 kg P_2O_5 ha^{-1} based on farmers´ practices recorded on previous studies from the study site (Stark, 2003). Both, N and P were applied in one time at planting time for every cropping season. For tree monoculture plantations, the simulation was run after monocropping maize in a non fertilizer scenario for four and a half years (estimated period when crop yield will declined below the profitable threshold under non-fertilizer conditions). Table 6.4 summarized all land uses scenarios simulated using WaNuLCAS model.

Table 6.4. Description of land use simulation scenarios run with WaNuLCAS

SIMULATION SCENARIOS	CODE	TIME (years/ cropping seasons)	FERTILIZER (kg*ha-1)	CROP	TREE SP
I. Maize Moncropping	Maize MC + Fertz	15 (30c.s)	45 N - 30 P	Maize	-
	Maize MC - Fertz	15 (30c.s)	-	Maize	-
II. Tree Intercropping	Tree IC + Fertz	15	45 N - 30 P	Maize	*S. contorta*
	Tree IC + Fertz	15	45 N - 30 P	Maize	*V. parviflora*
	Tree IC + Fertz	15	45 N - 30 P	Maize	*P. indicus*
	Tree IC + Fertz	15	45 N - 30 P	Maize	*S.macrophyla*
	Tree IC - Fertz	15	-	Maize	*S. contorta*
	Tree IC - Fertz	15	-	Maize	*V. parviflora*
	Tree IC - Fertz	15	-	Maize	*P. indicus*
	Tree IC - Fertz	15	-	Maize	*S. macrophyla*
III. Tree Monoculture	Tree MC	15	-	-	*S. contorta*
	Tree MC	15	-	-	*V. parviflora*
	Tree MC	15	-	-	*P. indicus*
	Tree MC	15	-	-	*S.macrophyla*

If applied to hedgerow intercropping systems, WaNuLCAS allows for the evaluation of crop growth at different distances form the tree hedgerow. With the objective to see the effect on how tree planting pattern affects the crop performance, the model was run at five different tree densities (50, 100, 200, 400, 800 trees/ha) as a result of combining three different levels of alley and intrarow spacing (Table 6.5).

Table 6.5. Tree spacing applied for WaNuLCAS simulation

ALLEY SPACING (meters)	INTRAROW SPACING (meters)	PLANTING PATTERN (meters)	TREE DENSITY (trees*ha^{-1})
20 (Wide alley)	2.5	20*2.5	200
	5.0	20*5.0	100
	10.0	20*10.0	50
10 (Middle alley)	2.5	10*2.5	400
	5.0	10*5.0	200
	10.0	10*10.0	100
5 (Narrow alley)	2.5	5*2.5	800
	5.0	5*5.0	400
	10.0	5*10.0	200

2.4. System analyses

Simulation model outputs were analysed from a system perspective with two different approaches: (1) Trade-off analysis between tree growth and crop yield; (2) Equivalent area index (EAI). Results from these two analyses will provide the necessary information to evaluate the feasibility and sustainability of all systems simulated.

2.4.1. Trade-off analysis between tree growth and crop yield

An efficient and innovative way of evaluating an agroforestry system is to plot crop versus tree yield (Figure 6.3) (SAFODS, 2005). If the tree-crop combinations are substantially above the straight 1:1 trade-off curve (X>1) it means that there is a net positive interaction within the system. However, when the points are below (X<1) suggest that there is virtually no intercropping advantage. If after accounting for this intercept, a positive curvature remains when tree spacing is widened, suggest that there is indeed a benefit to be obtained by the intercrop combination when compared to separate monocultures.

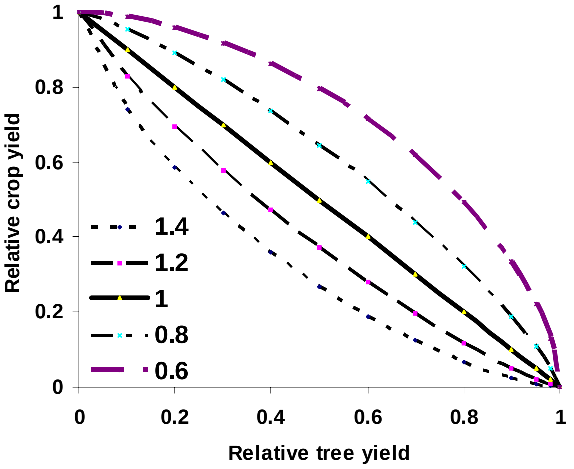

Figure 6.3. Trade-off between tree and crop yield, with net negative (X <1) or net positive (X>1) interactions

2.4.2. Equivalent area index (EAI) analysis

The ‘equivalent area index’ (EAI) is the second way of evaluate agroforestry scenarios and expresses the area of monocultures of trees plus crop that would be needed to achieve the same growth as obtained in intercropping (Willey and Osiru, 1972). When the index is equal to or higher than 1, it indicates positive interactions between the intercropped components and thus the system intercropping is technically feasible. When EAI analyses are presented on a yearly increment basis, it can be seen the way the systems changes allowing to evaluate and determine the age of tree which can still provide valuable crop yield. Calculations of the equivalent area production index (EAI) are based on the following formula:

$$EAI = EI_t + EI_c = \left(\frac{PI_t}{PM_t}\right) + \left(\frac{PI_c}{PM_c}\right) \quad (1)$$

Where: EAI = equivalent area index of the systems; EI_t = Equivalent Index of tree area; EI_c = Equivalent Index of crop area; PI_t and PM_t = tree productivity in intercropping and monoculture systems; PI_c and PM_c = crop productivity in intercropping and monoculture systems. Productivity of tree is using wood volume, m^3 ha^{-1}, while for maize is dry weight of grain, Mg ha^{-1}.

3. Results

3.1. WaNuLCAS tree growth predictions

Results from the validation test performed shows that model predictions precisely described tree growth for all three tree species with regards to stem diameter (Fig. 4.A), total aboveground biomass (Fig 4.C), wood biomass (Fig 4.D) and leaves biomass (Fig 4.E). For tree height (Fig 4.B.) the goodness of fit differed among species, with the largest deviations occurring for *Petrocarpus indicus*t (Figure 6.4).

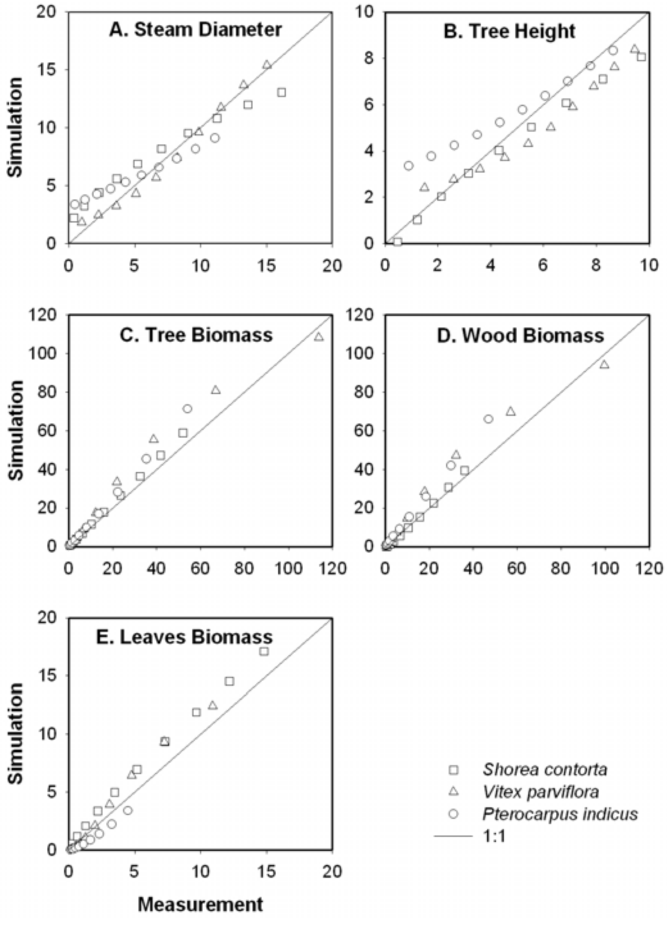

Figure 6.4. Comparison of simulated and measured tree growth over a ten years period: A. Tree Diameter (cm), B. Tree Height (m), C. Tree Biomass (Mg ha^{-1}), D.Wood Biomass (Mg ha^{-1}) and, E.Leaves Biomass (Mg ha^{-1}).

Statistical analysis also established the viability of model predictions for all tree species studied. Indeed, all tests performed confirm that WaNulCAS precisely simulate tree growth based on tree inputs parameters (Table 6.6).

Table 6.6. Statistical validation text for tree growth using WaNuLCAS according to Loague and Green (1991)

TREE SPECIES	DIAMETER	HEIGHT	TREE BIOM.	WOOD BIOM.	LEAVES BIOM.
All trees					
R^2	0.93	0.89	0.91	0.91	0.94
ME (0, ≥ 0)	3.07	2.46	42.14	28.96	21.95
RMSE (0, ≥ 0)	22.28	20.67	343.44	334.80	325.26
EF (1, ≤ 1)	0.89	0.86	0.68	0.83	-0.07
CRM (0, ≤ 1)	-0.06	0.04	0.42	0.29	0.70
CD (1, ≥ 0)	1.05	0.98	0.90	0.86	0.75
Shorea contorta					
R^2	0.98	0.99	0.99	0.99	0.97
ME (0, ≥ 0)	3.07	2.30	30.52	8.26	21.95
RMSE (0, ≥ 0)	25.87	19.39	52.20	24.72	77.68
EF (1, ≤ 1)	0.88	0.91	0.57	0.94	-0.44
CRM (0, ≤ 1)	-0.09	0.14	0.43	0.14	0.68
CD (1, ≥ 0)	1.00	1.00	1.00	0.80	0.78
Vitex parviflora					
R^2	0.98	0.96	0.89	0.91	0.88
ME (0, ≥ 0)	0.94	1.25	42.14	28.96	14.43
RMSE (0, ≥ 0)	7.69	17.06	53.73	47.01	84.67
EF (1, ≤ 1)	0.98	0.85	0.63	0.76	-0.44
CRM (0, ≤ 1)	0.01	0.12	0.44	0.36	0.73
CD (1, ≥ 0)	0.95	0.97	0.91	0.87	1.00
Pterocarpus indicus					
R^2	0.99	0.99	0.95	0.95	0.96
ME (0, ≥ 0)	2.86	2.46	15.27	9.03	8.95
RMSE (0, ≥ 0)	32.57	26.01	43.05	32.76	90.54
EF (1, ≤ 1)	0.75	0.75	0.79	0.89	-0.38
CRM (0, ≤ 1)	-0.11	-0.18	0.35	0.25	0.73
CD (1, ≥ 0)	0.87	0.96	0.74	0.87	0.34

ME: maximum error, RMSE: root mean square error, EF: model efficiency, CRM: coefficient of residual mass, CD: coefficient of determination.

3.2. WaNuLCAS simulation outputs

3.2.1. Length of cropping period

WaNulCAS model includes a rule that cropping will be automatically stopped after the first crop that reached a zero or negative net benefit, so the length of cropping period is now a model output, rather than input. Therefore the number of years cropping took place became a variable influenced by tree properties, tree spacing and growth conditions, rather than being a user-determined input as such.

Model predictions show clearly different opportunities for planting maize with or without fertilizer (Figure 6.5). In particular for maize monoculture in a non fertilization scenario with the existing site soil conditions, the length of the cropping period is only feasible during the first four years (eight cropping seasons) while under a fertilization situation maize yields were constantly maintained above the threshold level (Figure 6.5.A.1 and A.2). The effect of different tree species and planting patterns on maize cropping period was also captured by the outputs only under a fertilization scenario (Figure 6.5.B.1-C.1-D.1 and E.1). Major differences on maize yield were found due to widening effect of the alleys rather than the intrarow distance in between trees. For instance, in planting patterns with narrow alley (5 meters) maize was never feasible up to the end of the simulation, while for intermediate and wider crop alleys (10 and 20 meters) maize was feasible for continuous intercropping for all tree species with the exception of *Vitex parviflora* where yield will start to drop down after 20 cropping seasons (Figure 6.5.C.1)

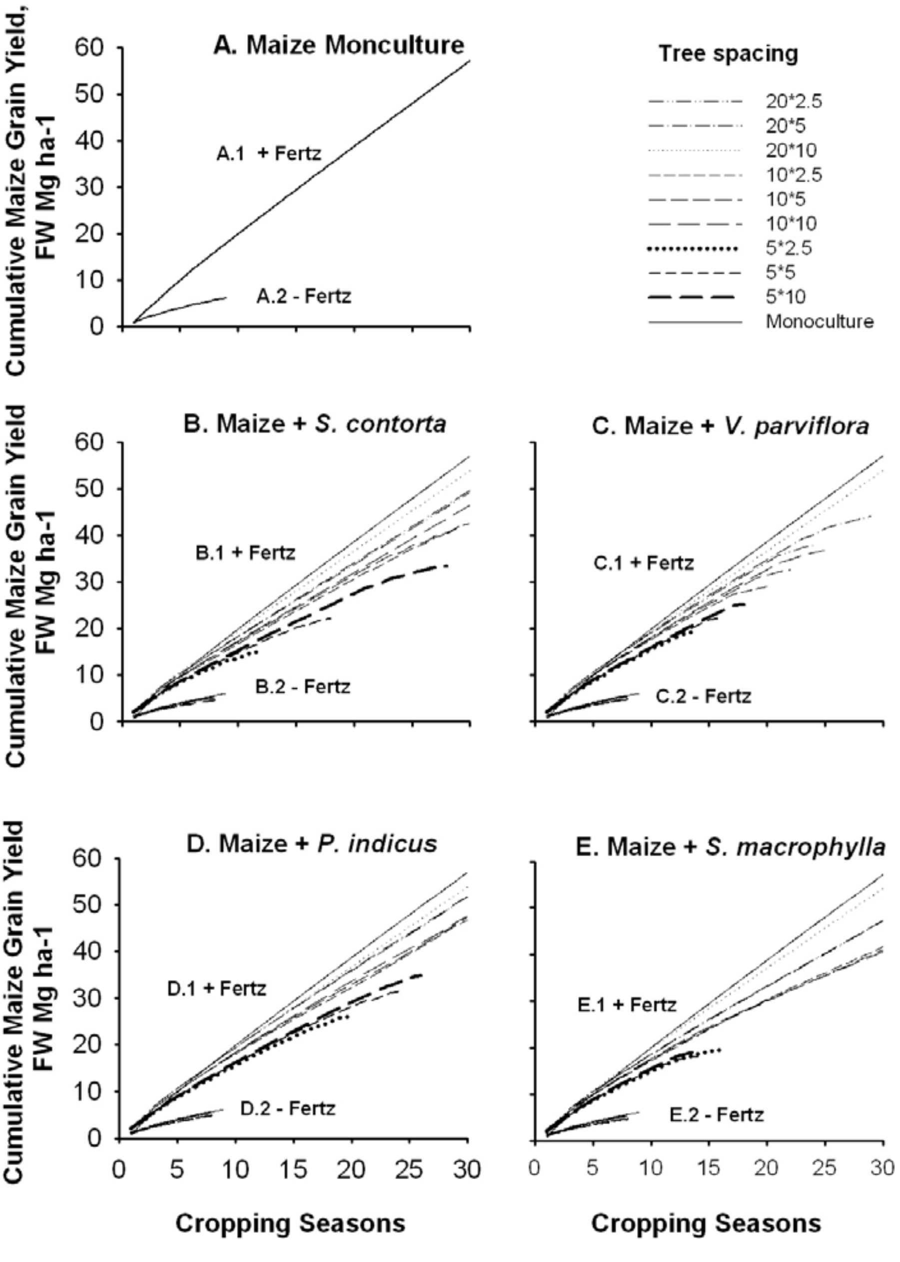

Figure 6.5. Length of cropping period under various tree spacing and fertilization conditions

3.2.2. Crop Yield

If above results are converted into cumulative maize yield up to the end of the simulation, it is clearly seen that there is a trade-off between the tree and crop yields: lower tree densities lead to a proportional gain in maize productivity (Figure 6.6). In a fertilization intercrop scenario, maize yield is significantly influenced by tree density, spacing arrangements and species selected for the systems. If the priority is given to the tree of the final tree-crop combination (targeting maximum tree density, 800 trees ha^{-1}) average predicted cumulative maize yield will be 20 Mg ha^{-1}, which represents only 1/3 from the total yield that could be harvest on a maize monoculture scenario. Instead, if the priority is given to the crop (targeting minimum tree density, 100 trees ha^{-1}) the system still allows close to 90% of monoculture crop yield.

By contrast, based on this results, in a non fertilization scenario maize monocropping or intercropping (regardless the tree species or planting pattern) is not a feasible and sustainable option for farmers on degraded soils. The low productivity in terms of maize yield (almost 10 times less than in a fertilization scenario) shows that agroforestry options are not better than monoculture under these conditions.

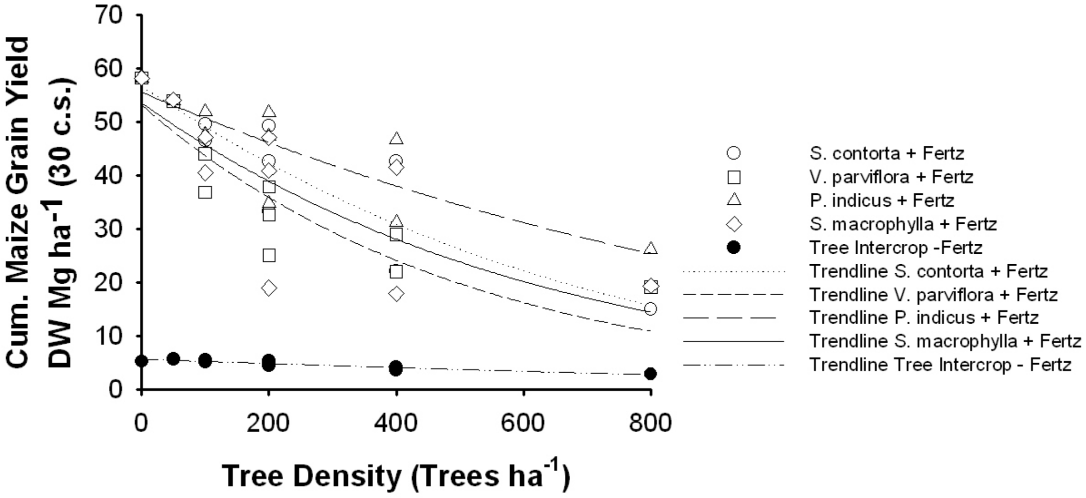

Figure 6.6. Cumulative maize yield during 30 cropping seasons for monoculture and intercropping systems

3.2.3. Tree Performance

One clear advantage for intercropping systems, as seen in these results, is that trees directly benefit from the inputs (i.e. fertilizer) that are applied to the crops (Figure 6.7.A and 6.8.A). All tree intercrop systems under fertilization conditions, substantially increased their tree performance (in terms of wood volume and stem diameter) if compared to the same systems without fertilizer (Figure 6.7.B and 6.8.B). By contrast, tree monoculture plantations have almost the same tree growth as tree intercropped system without fertilizer showing that even under these conditions there are some opportunities for simultaneous agroforestry systems (Figure 6.7.C and 6.8.C). At the species level, *Ptercarpus indicus* showed the best response at higher tree density and *S. macrophylla* at lower tree densities. *S. contorta* constantly showed the lowest tree performance for all tree systems studied. Results from the simulation also show that higher tree densities produce higher wood volume but lower tree diameter growth (Figure 6.8).

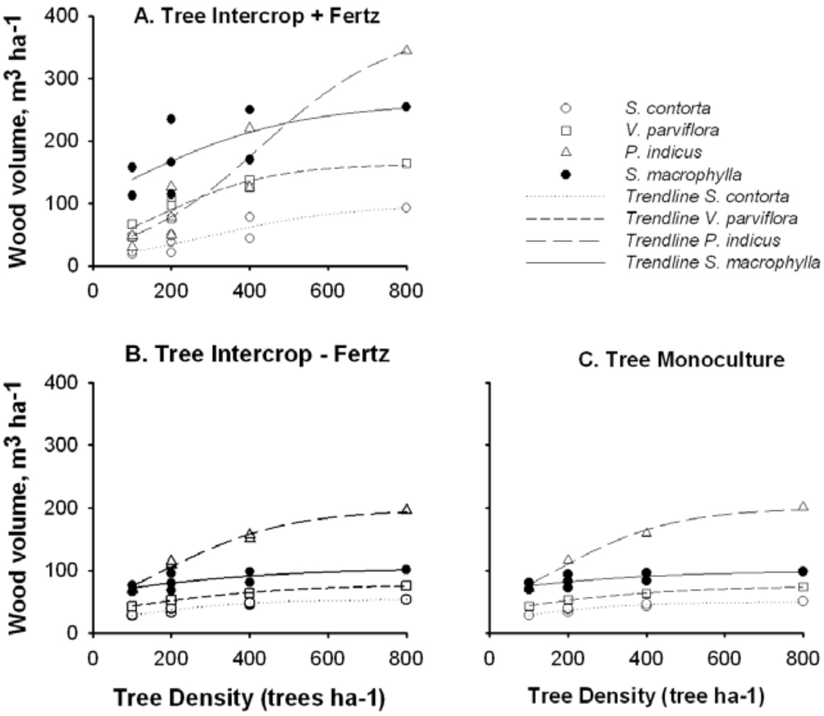

Figure 6.7. Wood volume prediction for tree intercrop and monoculture systems for a period of 15 years

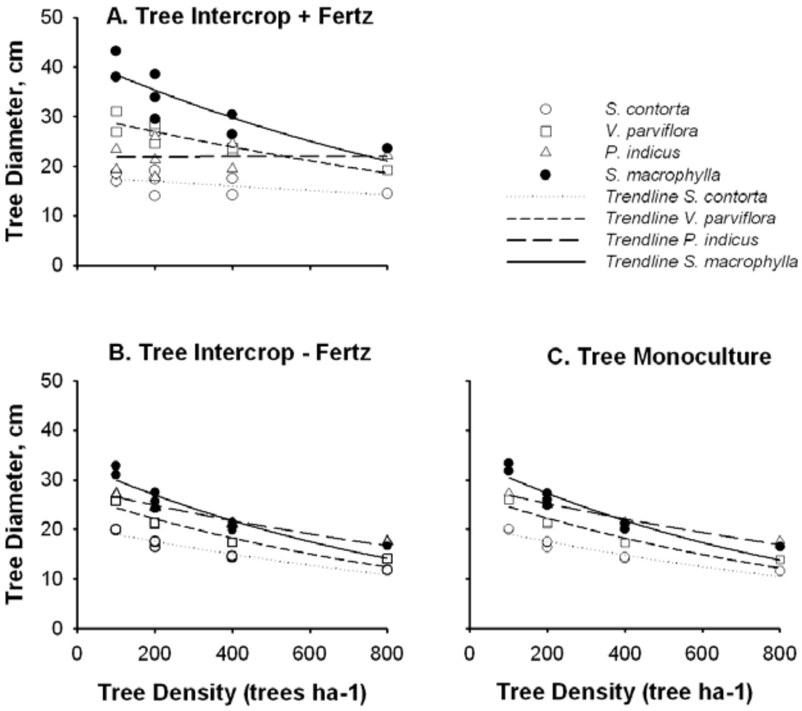

Figure 6.8. Stem diameter prediction for tree intercrop and monoculture systems for a period of 15 years

3.3. Systems evaluation

3.3.1. Trade-off evaluation

All tree-crop combinations of intercrop system with fertilizer are substantially above the straight trade-off curve, suggesting that there is indeed a benefit to be obtained by the combination when compared to separate monocultures (Figure 6.9). After accounting for this intercept, the slight positive curvature of trend line for *V. parviflora* and *S. macrophylla* that remains when tree spacing is widened, suggests a clear intercropping advantage at intermediate tree population densities for these two species. Based on these results *V. parviflora* stood out as the most promising 'agroforestry' native tree specie.

Generally, results from trade-off analysis show that there is considerable scope for agroforestry with all tree species studied, with systems that yield about half of the maximum tree biomass still allowing 70% of monoculture maize yield. Maximum tree yield can be obtained at about 40% of the potential crop yield. Although, when low tree densities (100 trees/ha) are targeted to increase the ratio between wood volume and stem diameter for better quality wood products, intercrop systems will still allowed close to 90% of the potential maize yield. However, results shows that the intercropping advantage will also depend on the tree species and spacing selected. Trade-off analyses under non-fertilization scenarios are not presented as crop failures meant that no intercropping advantage was obtained under these conditions, according to the model.

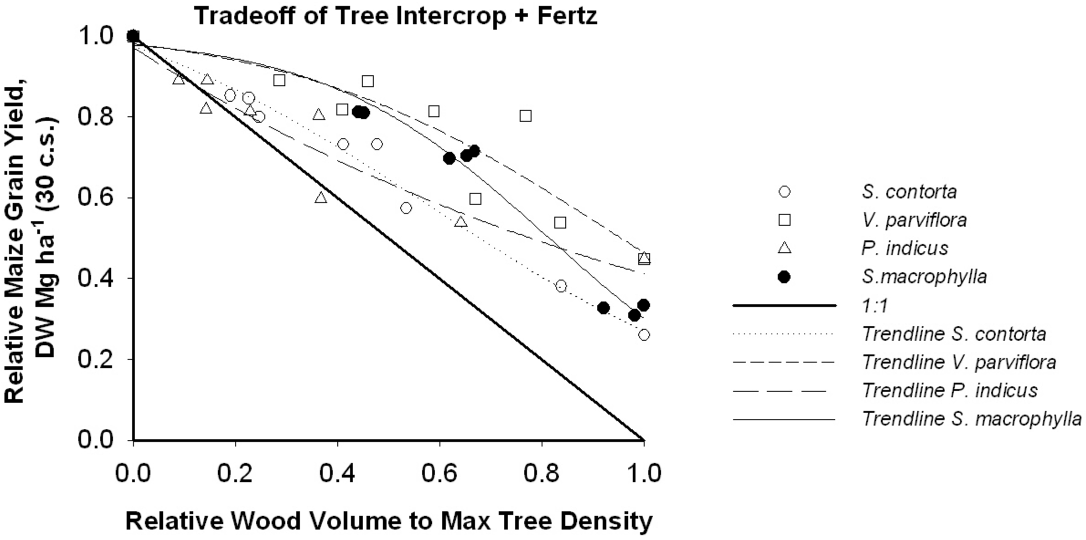

Figure 6.9. Trade-off analyses between tree and crop interactions for simultaneous intercrop systems

3.3.2. Equivalent Area Index (EAI) evaluation

As the EAI evaluation is presented on a yearly increment basis, results clearly show that after an initial stage (4 to 5 years where by definition 'wood increments' only start after the tree stem diameter reached 10 cm), the accumulating value between the tree plus crops makes all intercrop systems studied technically feasible (EAI>1) (Figure 6.10). During the initial stage, where the interaction between trees and crops are very high, the system can still provide valuable crop yield but as soon as the tree yield starts to increase above the threshold level the crop will start to decline. Besides this interaction effect between the components, maize productivity was sustainable up to the end of the rotation period for all tree intercrop systems with the exception of *Vitex parviflora* (Figure 6.10.B). As the trees benefit from the inputs applied to the crops in intercrop systems, results suggest that there is a remarkable advantage for the wood which increases the land productivity within a range of 1.5 to 2.5 times than in unfertilized tree monoculture systems as comparison.

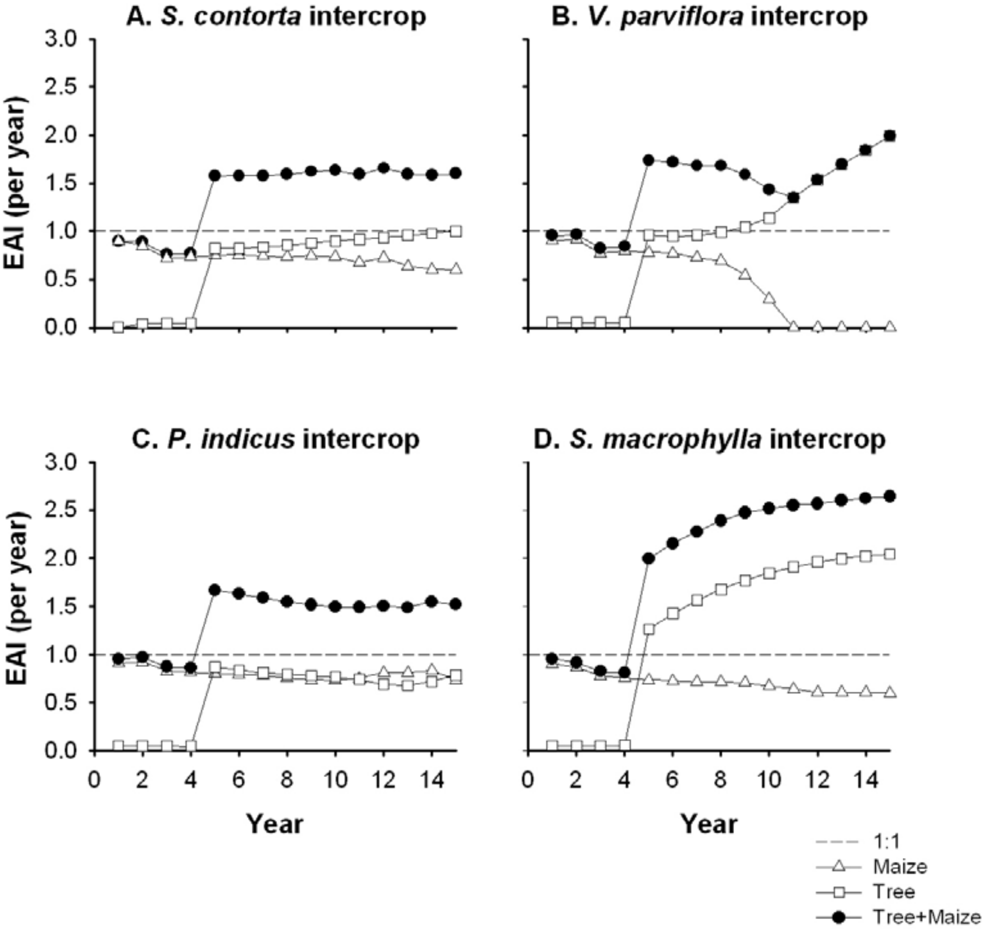

Figure 6.10. Equivalent Area Index analysis presented on a yearly increment basis (Note: by definition 'wood increments' only start after the tree stem diameter reached 10 cm)

4. Discussion

A focal point in the analysis of where and how agroforestry systems work is still whether or not tree-crop systems can utilize resources of light, water and nutrients which would not be used in a simpler tree or crop system (Cambell *et al.*, 1996). A fair amount of detail in the description of above and below ground resource capture by the component species is needed to evaluate both competition and complementarily (Sanchez, 1995; Ong and Huxley, 1996).

Tree-soil-crop interactions occur both in space and time (Yin and He, 1997). In "sequential" agroforestry systems neighbourhood effect in a landscape mosaic still have a spatial element, while "simultaneous" systems often have at least an element of zonation (van Noordwijk and Lusiana, 1999). The dichotomy between sequential simultaneous agroforestry systems may thus have been overstated in the past and a modelling framework is desirable in which they are endpoints of a continuum (Sanchez, 1995; van Noordwijk and Prunomosidhi, 1995). Thus, in modelling agroforestry systems, a balance should be maintained between process and pattern, between temporal and spatial aspects.

Models can be of value if it can cover essential aspects of real-world behaviour (van Noordwijk *et al*., 2004a). The WaNuLCAS model was developed as an agroforestry prototype, not including all possible tree-soil-crop interaction relationships that one can imagine, but to incorporating a core of relations which are fairly sure of for each specific case (van Noordwijk and Lusiana, 1999). As a whole, model calculations may present a reasonable correspondence with real world options, although no experimental data sets exist on the same agroforestry system at the same soil but widely differing rainfall conditions. Any of the results mentioned here would vary with parameters such as soil depth, soil texture, tree canopy characteristics and rooting pattern but the basic pattern of response to climate zones would remain determined by overall resource availability. In this sense the model can be viewed as a "null model" (Gotelli and Ruth, 1994) which can be used like a null hypothesis as a background against which specific data sets can be tested.

Overall this study simulated different timber based agroforestry system to evaluate the technical feasibility of native trees to be intercrop with maize under a wide array of possible management options. Generally, results from the simulation show that there is considerable scope for agroforestry intercropping native timber tree species if the crop is fertilized. However, results also shows that the intercropping advantage will depend on the tree species and planting pattern selected. For example, for *V. parviflora* and *P. indicus* maximum tree yield can be obtained at about 50% (30 Mg ha^{-1}) of the potential crop yield, while for *S. macrophylla* and *S. contorta* will be at 30% (20 Mg ha^{-1}).

The distribution of nutrients, water and light, below and above ground level among trees and annual crops was influenced mainly by the characteristics of those tree species as components in an agroforestry system. Generally all species studied, have appropriate crown shapes which allow an optimal balance among trees and crops for both ecosystem and agricultural purpose. However, not all species with those tree characteristics may be adapted to stress environments, such as poor degraded soils from the study site. For example, *Shorea contorta* show a poor response when planted under these conditions in an agroforestry situation. Possibly because *Ptercarpus indicus* is a nitrogen fixing tree and therefore reduce below ground nutrient competition, seems to be better adapted to these conditions than the other three species included in the study.

As seen from the results, there is a trade-off between the tree and crop where higher tree densities will lead to a proportional loss in maize productivity; for some situations the loss is more than proportional, for others less than proportional and an 'intercropping advantage' can be obtained. Depending on the priority of farmers given to either of the component, will be determinant when considering the choice of the final tree-crop combination. One way to reduce the detrimental effect of timber trees on crops when planted in association is by manipulating tree planting pattern by reducing the tree-crop interface i.e., the "intimacy" between plant components (Huxley, 1999). For each tree-crop combination simulated, increasing the rectangularity (i.e. increasing the ratio of inter-row to intra-row spacing) would enhance yield of intercrops in around 30% depending on the system. For example, in a system with 400 trees ha^{-1} planted of *Pterocarpus indicus* at 10x2.5 m there are 1,000 linear meters (lm) ha^{-1} of tree-crop interface, this system will yield at the end of the rotation period 46.78 Mg ha^{-1} of maize grain yield; While if trees are arranged at 5x5 m there are 2,000 lm ha^{-1} of tree-crop interface (maintaining same tree density, 400 trees ha^{-1}) the system will only yield 31.34 Mg ha^{-1}.

Therefore, increasing the space between tree rows makes longer intercropping possible but reduces the expected wood yield from the trees. For example, 400 trees ha^{-1} planted of *Pterocarpus indicus* at 10x2.5 m will produce at the end of the rotation period 124.93 m^{3} ha^{-1} of wood volume; while if trees are arranged at 5x5 m the system will yield 220.28 m^{3} ha^{-1}. This represents an increase on the tree biomass of around 40% depending on the tree specie. Beside this loss on wood volume, closer intra-row spacing provides the side shading needed to promote good stem form of timber trees (Gajaseni and Jordan, 1992; Huxley, 1999).

The response of the model in regards to tree growth performance primarily depends on the ability of trees to utilize potential canopy space that they get in wider plant spacing and to at least partially compensate for the lower plant density by a larger size per tree. As a consequence, higher tree densities produce higher wood volume but lower tree diameter growth. For example, if 200 trees ha^{-1} of *Pterocarpus indicus* are planted in a monoculture system, the expected wood volume to harvest after the rotation period would be 116 m^3 ha^{-1} with an average stem diameter of 25.0 cm per tree; while if 800 trees ha^{-1} are targeted, the wood volume would be 201 m^3 ha^{-1} but with an average stem diameter of 17.7 cm. Therefore, if economic value depends on individual stem diameters rather than total wood volume, economic optimization may differ from maximising productivity and lower tree densities should be considered.

One clear advantage of simultaneous intercropping systems, as confirm form these results, rather than sequential monoculture systems is that trees directly benefit from the inputs (i.e. fertilizer) that are applied to the crops (Saxena, 1991). The intensive land preparation for crops also ensures tree survival, promotes growth, while the costs of tree establishment can be (in the mind or cash flow of the farmer) charged to the intercrop (Garrity, 1997; Bertomeu, 2004). However, the final choice of tree species and planting pattern would depend on the economic feasibility of wood and crop production (Huxley, 1999). If considered that there is a remarkable intercropping advantage to the wood (in a range of 1.5 to 2.5) and the high potential market value of good quality timber, agroforestry system with selected native trees should be an economic attractive alternative for many farmers.

Additionally, maize monocropping system are only a productive option for farmers on degraded soils, if poor soil conditions are partly offset by mineral fertilizer use (subsidised production system), accepting high erosion soil losses as a consequence (Ong and Huxley, 1996). The rapid decline of maize yield based on model simulations, allows for only 4 to 5 cropping season with production above the threshold level confirm this idea. Thus, if farmer can afford the use of fertilizer, a gradual transition from annual food crop to tree-based systems should be promoted by extension agents as a more sustainable and environmentally sound alternative. This idea is in line with other studies and actors involve in the decision making process in the Philippines (Gacososcosim, 1995; DENR, 1998; Bertomeu 2004).

For those poor farmers who cannot even afford the use of external inputs (i.e. fertilizer) results form this study show that tree-based agroforestry systems do not provide better perspective than monoculture systems. The unfortunate consequence of this situation is that poor households often face other important labour, land, and cash constrains on their availability to invest on land improvements. To meet the objective of poverty alleviation, however, it is crucial that market expansion and creation are possible, hence for example it is important to determine which marketable traits are amenable to improvement. While some traits that are relatively easy to identify do benefit the farmer, there are undoubtedly others that are important to the food, pharmaceutical or other industries that require more sophisticated evaluation (Leaky and Simons, 1997).

Overall, with this approach is not expected to find fixed recipes of ‘best practice’ combinations, rather it will show that the model tool use for predicting response is useful so that the end results (in aggregate terms such as trade-off) can be robust and buffered against external variability. Rather than identifying the particular combination that maximizes the outputs, it is emphasize domains where the tradeoffs between multiple functions have at least some yield benefit stemming from ‘complementarities’ (van Noordwijk *et al*., 2004a).

5. Conclusions

- Timber-based agroforestry systems with native species are a technical feasible and sustainable land use options for farmers who can afford the use of external inputs (i.e. fertilizer) applied only to the crop.
- For all three native trees species studied, there is considerable scope of intercropping advantage compare to monocropping system; where *Vitex parviflora* stood out as the most promising 'agroforestry' native tree at intermediate densities.
- *Swietenia macrophylla* have a similar range for intercropping advantage than native trees studied, suggesting than extension agent should increased the number of tree options to be promoted with especial attention to some native species.
- There is a trade-off between the tree and crop occurring and depending on the priority given to either of the component which will be determinant when considering the final choice of tree-crop combination.
- Widening the space between tree rows makes longer intercropping possible but proportionally reduces the expected yield from the trees.
- Trees growth partially compensated in tree diameter lower tree densities. If tree value depends on individual stem diameters rather than volume, economic optimization may differ from maximising productivity.
- The final choice of tree species and planting pattern would depend on the economic feasibility of wood and crop production, however results confirm that there is with a remarkable intercropping advantage on the wood production side.
- A gradual transition from pure crop monoculture to timber-based systems seems to be a feasible and sustainable land use alternative from a biophysical point of view.

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7. WILL TIMBER BASED AGROFORESTRY SYSTEMS OFFER BETTER ECONOMIC PROSPECTS?

Profitability and risk assessment of timber based agroforestry systems

Abstract

Agroforestry system has long been recognized as a sound strategy to cope with price and crop yield variability, thus increasing farm income stability and lowering financial risk. However, this general assumption needs to be tested under site specific conditions. The general objective of this study is to assess if timber based agroforestry systems are an economically feasible alternative for smallholder farmers in terms of: (1) profitability, (2) labour requirements and, (3) reduction of economic risk. Study results evidence that agroforestry systems indeed offer better social financial prospect although, with the existing policies and market conditions in the Philippines, these benefits are not yet perceived by farmers. Particularly, timber export charges and high transaction cost endow with an important financial social benefit for planting timber trees. The Philippine government should seized this economic opportunity by promoting tree planting activities, either by standard reforestation or agroforestration programs. Additionally, tree intercrop system will be an effective household strategy to reduce labour requirements only if primary attention is given to the tree instead to the food crop. Sensitivity analysis results shows that maize monocropping systems are expose to real economic risk while tree intercrop systems are buffered form external variability changes. Final discussion evaluates which are the conditions at the macroeconomic as well as the local level that may constrain or favour agroforestry adoption. Concluding that if exist a real interest form Philippine government to introduce tress for recovering degraded landscapes and improve rural livelihoods, specific changes on existing policies might be prior needed.

1. Introduction

In most cases smallholders grow timber as a commodity, not for the intrinsic value of the tree (Hatch and Naughton, 1994; Wickramasinghe, 1994; Otsamo and Sumantri, 1999; Malla, 2000). In the Philippines, tree planting began to be promoted as and exceptionally profitable farm enterprise as a result of extensive deforestation and increasing timber demands (Bertomeu, 2004). In the early 80s, when the price of timber was high farmers were promised[10] huge returns from tree farming. Farmers seized this economic opportunity by planting fast-growing timber trees, such as *Gmelina arborea* Roxb., *Paraserianthes falcataria* L. and *Acacia mangium* Willd. as a cash crop (Garrity and Mercado, 1994). However, widespread planting of few fast-growing timber species led to oversupply and subsequently a sharp decline in the price of farm-grown timber.

Agricultural producers and consumers are heavily influence by macroeconomic policies even though they often have little influence over the setting of these nation-wide polices. Three categories of macroeconomic policies, monetary and fiscal policies, foreign exchange rate policies, and factor price, natural resource, and land use policies, affect agriculture (Person *et al.,* 2004). To sustain the viability of particular agricultural commodities or techniques of production, either domestic consumers had to pay higher prices or governments had to subsidize production cost to maintain international competitiveness. In general, economists, policy-markers, and development institutions have reached a consensus on the importance of these investments (Monke and Pearson,

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[10] The popular Filipino saying “Kahoy karon, bulawan ugma” (trees today, gold tomorrow) reflects the over-expectations put on tree farming.

1989). These commodity-specific policies include taxes, subsides, and quantitative controls on particular outputs and inputs and policies that affect the macroeconomic conditions (interest rates, wage rate and exchange rate).

As describe by Pearson *et al*. (2004) decision makers are assumed to have broad objectives that they are trying to further through interventions in the agricultural sector. The three most common objectives are efficiency (the allocation of resources to effect maximal output), income distribution (the allocation of the benefits of agricultural production to preferred groups or regions), and food security (the short-run stability of food prices at levels affordable to consumers, reflecting the adequacy of food supplies, and the long-run guarantee of adequate human nutrition). Government actions that can further all three objectives are likely to be taken. Typically, however, the promotion of one objective conflicts with one or both others. For example, small losses in efficiency might be tolerated if the action were believed to result in significant improvements in income distribution or food security. Policy makers make these tradeoffs explicitly or implicitly by forming value judgments about the worth of different objectives. Thus, a well-understood framework for agricultural policy analysis is needed for decision-makers and interest groups to understand the consequences of policy actions (Photo 7.1).

Photo 7.1. Agricultural practices on traditional steep forest lands

The Policy Analysis Matrix[11] (Monke and Pearson, 1989) is a matrix of information about agricultural and natural resource policies and market imperfections that is created by comparing multi-year land use system budget calculated at private and social prices. Private prices are the prices that farm households are facing (local or domestic market price of input and output). Therefore profitability or net present value (NPV) appreciated at private prices, so called private profitability, is an indicator for production incentive. Social prices are the economic prices that remove the impact of policy distortion (taxes, subsidy and other local levies) and market imperfections. Usually it is derived from export or import parity prices of particular inputs or outputs. Profitability measured at social prices, so called social profitability, is an indicator of potential profitability (Tomich *et al.*, 1998).

The approach used in PAM analysis begging with the calculations of existing levels of private (actual market) and social (efficiency) revenues, cost, and profits. This calculation reveals the extent to which actual profits are generated by policy transfers rather than by underlying economic efficiency. Next, agricultural scientists need to project changes in yield and inputs resulting from

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[11] The PAM approach was first developed in 1981 by researchers at the University of Arizona and Stanford University to study changes in agricultural polices and projects in Portugal. Since then, PAM has been described and applied widely in the literature on agricultural development. A concise summary can be found in Monke and Pearson (1989).

alternative research programs. The effectiveness of such changes can then be gauged by an examination of how they alter private and social profits of current technologies. An understanding of the array of social profitability of agricultural systems greatly reduce the number of detailed benefit-cost analyses needed to evaluate investment alternatives.

The standard approach to agricultural policy analysis relies on estimated elasticity of supply and demand. When economic polices changes, use of the elasticity permits to quantify the robustness of production systems to changes. Without sufficient information (such the as elasticity of output and input demand), exact PAM analysis cannot be constructed, and approximations must be made. Unless this is done, PAM results will show nothing more than a set of diagrams, with little understanding of how the many divergences affecting agricultural system offset one another, and no input into the policy making process (Monke and Pearson, 1989).

Smallholder farmers are a very important group of stakeholders in the search for "best bet"[12] land-use system (Tomich *et al.*, 1998). The decision of a household to follow a particular livelihood strategy is the outcome of a fine-tuning of objectives to their possibilities and constrains. Following the theory of "livelihood strategies" (Chambers and Leach, 1987) small-scale farmers are "welfare maximisers" and base their decisions, including the adoption of a certain land-use system, on the extent to which their potential alternatives fulfil their private household objectives. More than maximizing returns to capital, smallholders seek to maximize returns to their productive resources or those resources perceived to be the most scarce or valuable. When farming is the major activity of the household, returns to land and labour may be most critical (Scherr, 1995).

Risk reduction is other important objective in livelihood strategies of small-scale farmers (Amacher *et al.*, 1993). Households´ attitudes toward risk and expectation of uncertain gains form adoption were among the most critical factors in adoption of alternative land-use system (FAO, 1986). The degree to which households will try to reduce the amount of risk depends on their resource position. For example, the associate risks involved in growing trees differ from those for food crops (i.e. uncertainty of long term trends in prices), this is in itself one of the potential advantages of agroforestry, but also poses a challenge for farmers converting part of their farm to agroforestry (Photo 7.2).

Photo 7.2. Household who have practised agroforestry from long time

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[12] Tocmich *et al.* 1998, define a best bet land-use system as "a way to manage land resources that, when supported by necessary technological and institutional innovation and policy reform somehow takes into consideration the local private and global public goods and services that supply".

Agroforestry system has long been recognized as a sound strategy to cope with price and crop yield variability, thus increasing farm income stability and lowering financial risk (van Noordwijk and Ong, 1999). Alternative systems and technologies must be profitable and socially acceptable for smallholders; if not they have little prospect for adoption and, hence, impact (Tomich *et al.*, 1998; Vosti *et al.*, 2000). In many areas of the Philippines farmers are starting to spontaneously plant native timber species in limited numbers for home-use or local sale. Although this species may have excellent wood properties, they are under-valued by commercial markets, which are based on the dependable production of timber species with recognized characteristics (Leakey and Simons, 1998). A minimum set of three quantifiable socioeconomic objectives are judged necessary for the assessment of land use alternatives from smallholders´ perspectives. Does it pay smallholders to invest in a particular production alternative compared with other options? Is it feasible for these households to supply the necessary labour themselves or to hire workers? Even if the alternative is profitable and feasible given household labour constrains and labour-market conditions, is it to risky (either in terms of variance in food yields or as a source of income) that adoption would jeopardize livelihood strategy?

The overall objective of this study is to assess if intercropping native timber with associate food crops are an economically feasible alternative for smallholder farmers in terms of: (1) profitability, (2) labour requirements and, (3) reduction of economic risk. Other aspects that will be discussed are the opportunities that exist for changing policies or market conditions that may constrain or favour adoption.

2. Materials and Methods

2.1. PAM analysis

Policy Analysis Matrix (PAM) is the representation of two basic identities, the first of which defines the profitability as the difference between income and cost (rows), whereas the second measures the effects of the differences in incomes, cost and profits arising form distorting policies and market failures (columns). By filling in the elements of the PAM for an agricultural system, it can measured both the extent of transfers occasioned by the set of polices acting on the system and the inherent economic efficiency of the system (Table 7.1).

Table 7.1. Policy Analysis Matrix (Source: Monke and Pearson, 1989)

	INCOME	**COST**		**PROFITS**
		Tradable inputs	*Domestics factors*	
Private prices	A	B	C	D
Social prices	E	F	G	H
Effects of divergences and efficient policy	I	J	K	L

The rows of the matrix respectively represent:

1. *Private profitability* (D = A- B – C). The term of *private* refers to observe revenues and cost reflecting market prices received or paid by farmers in the agricultural systems. Private profitability calculations show the competitiveness of agricultural systems at given current technologies, output values, import cost and policy transfer.
2. *Social profitability* (H= E – F – G). Social profits are efficiency measures, because output and input are valued in prices that reflect scarcity or social opportunity cost. Social valuation of output (E) and input (F) that internationally tradable, are given by international market prices.

Social valuation for domestic factor (G) are found by estimation of net income forgone because the factor is not employed its best alternative use or its opportunity cost (Monke and Person, 1996)

3. *Effects of the divergences*. Any divergence between the observed private prices and the estimated social prices must be explained by the effect of policy or by the existence of market failure. *Output transfer* (I = A – E) and *input transfer* (J=B – F), arise from two kinds of policy that cause divergence between observed market prices and world product prices. Those two kind of policies are commodity-specific policies include a wide range of taxes and subsidies and trade policies, and exchanged rate policy. *Factor transfer* (K= C – G) show how policies on factors of production and the factor market imperfection had been taking place that create a divergence between private cost (C) and social costs (G). The *net transfer* (L = I – J – K) represent a net balance from the application of combination of policies that create economic distortions (i.e. trade protection, price support, exchange rate misalignment), market failures, and correcting policies that aim to restore efficiency conditions. Positive entries in two cost categories, J and K represent negative transfer because they reduce private profit, whereas negative entries in J and K represent positive transfer.

The columns of the matrix show *income* and *profits*, as well as the break down of cost into two columns, form by the *tradable inputs* and *domestic production factors* (capital, land and labour). The so-called *intermediate inputs* (i.e. fertilizers, improved seeds, transport) must also be decomposed into elements of the *tradable inputs* type, and into *domestic factors* components. This process of disaggregating intermediate goods or services separates intermediate cost into four categories: tradable inputs, domestics factors, transfers (taxes or subsidies that are set aside in social evaluations), and non tradable inputs (which themselves have to be further disaggregated so that ultimately all component cost are classified as tradable inputs, domestic factors, or transfers).

2.2. Data need for PAM analysis

Each PAM requires a set of essential data on agricultural activities, the market prices of any agricultural inputs as well as its output and its comparable social prices, for each related agricultural system included in the analysis. For this study the agricultural systems compared through the analysis are: Maize monocropping and four intercropped scenarios using different tree density (100 – 200 – 400 and 800 trees / ha) and four different tree species, *Shorea contorta* Vid., *Pterocarpus indicus* Juss., and *Vitex parviflora* Willd. and *Swietenia macrophylla* King. By choosing this subset of agricultural systems it aims to asses if tree intercrop systems can offer better economic prospect than maize monocropping production systems under the present macroeconomic conditions prevailing in the Philippines.

2.2.1. Farm level budgets: Input-Output data

Empirically PAM analysis begins with the compilation of “synthetic” farm budgets. These budgets are synthetic in two senses, they are not the result of original fieldwork and thus are somehow artificial, and they are synthesis of existing work. Ideally, actual field work should be carry out on completion, verification, and updating of the synthesis budgets, however it is also expensive and requires a lot of time and resources. The budgets data needed for PAM entries can be also based on reliable sources of information based on a wide range of informed and expert opinion about agricultural systems rather than meet imposed standards of large field sample size (Pearson *et al.*, 2004).

A farm level budget is constructed for each activity of the system. Input data collection begins with compilation of an inventory of tradable inputs required for each system (Table 7.2). These items are categorized, quantified, and priced, first in private and then in social terms. The cost and returns of each activity are added together to generate the total cost and returns for the commodity system.

The second category of input, direct labour, covers all labour directly employed in the activity. This category does not include all the labour used by the system, because some labour will be indirectly employed as a consequence of the use of intermediate inputs by the activity. Keeping separate the direct labour inputs facilitates the analysis of employment effects of the system.

Table 7.2. Input data collection in farm activity budgets for each system

ITEM	UNIT	MAIZE MC	100 TREES IC	200 TREES IC	400 TREES IC	800 TREES IC
Tradable Input						
Fertilizer						
Urea	*kg/ha*	196.0	186.0	176.0	166.0	157.0
TSP	*kg/ha*	133.0	124.0	117.0	111.0	104.0
Planting Material						
Seeds Maize	*Kg/ha*	40.0	38.0	36	34.0	32.0
Seedlings	*Seedlings/ha*	0.0	100.0	200.0	400.0	800.0
Labour						
SAB	*ps-day/ha*	7.0	7.0	7.0	7.0	7.0
Land preparation						
Plowing	*ps-day/ha*	30.0	28.5	27.0	25.5	24.0
Planting						
Maize	*ps-day/ha*	50.0	47.5	45.0	42.5	40.0
Trees	*ps-day/ha*	0.0	2.0	4.0	8.0	16.0
Management						
Weeding						
Maize	*ps-day/ha*	16.0	16.0	16.0	16.0	16.0
Trees	*ps-day/ha*	0.0	0.0	0.0	0.0	0.0
Fertilization						
Maize	*ps-day/ha*	4.0	3.8	3.6	3.4	3.2
Trees	*ps-day/ha*	0.0	0.0	0.0	0.0	0.0
Harvesting						
Maize	*ps-day/ha*	4.0	3.8	3.6	3.4	3.2
Trees	*ps-day/ha*	0.0	20.0	40.0	80.0	160.0

The final category of the activity budget, cover all outputs of the system. To prepare farm budgets, it is needed complete familiarity with production systems in a yearly basis (see ANNEX 5 for example of detail farm level description and budget). Results from WaNulCAS 3.1 model simulations from previous study (Chapter 6) were used as the output data to prepare detailed farm budgets (Table 7.3). As these output data has pass through a process of validation from the biophysical perspective, it can be considered as a reliable source of information to estimate the productivity of each system.

Table 7.3. Output data for each agricultural system based on model simulations

AGRICULTURAL SYSTEM	MAIZE GRAIN (Kg*ha^{-1})	TIMBER (m^{3} *ha^{-1})
Maize Monoculture	381.5	0
100 trees IC *S. contorta*	49.7	18
100 trees IC *V. parviflora*	44.2	47
100 trees IC *P. indicus*	51.9	30
100 trees IC *S. macrophylla*	47.5	112
200 trees IC *S. contorta*	42.7	38
200 trees IC *V. parviflora*	32.7	97
200 trees IC *P. indicus*	47.5	78
200 trees IC *S. macrophylla*	40.9	115
400 trees IC *S. contorta*	42.6	44
400 trees IC *V. parviflora*	29.1	126
400 trees IC *P. indicus*	46.8	125
400 trees IC *S. macrophylla*	41.6	166
800 trees IC *S. contorta*	15.1	93
800 trees IC *V. parviflora*	19.3	164
800 trees IC *P. indicus*	26.2	196
800 trees IC *S. macrophylla*	19.5	255

2.2.2. Prices and Macroeconomic assumptions

An equally important aspect of farm level budgets involves the estimation of prices for all inputs and outputs. In general in determining the prices the study uses annual average prices of all tradable farm inputs and farm commodities cast from reliable sources. The study uses local market prices as the basis of calculation of farm budget valued at private prices. Whereas for the comparable farm budget at social prices, the study applies export or import parity prices at farm gate as the basis of calculation.

However, for some items, local market prices will not exist because the product is produced and consumed exclusively on the farm. This is the case of timber price for many native tree species, where wood products haven't been trade on the markets for decades. To solve this situation, it was created market-equivalent values of native timber based on F.O.B[13] market prices of forest products determined by the Department of Natural Resources (as amended in RA No. 7163[14] from the Revised Forestry Code, 1991). Form this F.O.B. market price (social price) to calculate the actual market price at farm gate (private price); it was first deducted twenty-five percent (25%) of the actual F.O.B. market price in order to pay government taxes (as amended by RA No. 7161[15]) and secondly an other twenty five percent (25%) to cover product margin share as transportation and transactions costs. Estimations on margin shares were based on expert opinions from agricultural researchers with long experience in econometric analysis.

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13. F.O.B. price refers to Free On Board price or most commonly known as Port Price

14. RA No. 7163, 10 Oct. 1991: The actual F.O.B. market price of forest products shall be justly determined once a year by the Secretary of Environment and Natural Resources: Taking into consideration production cost (developing cost, contingencies and miscellaneous cost), species and

15. RA No. 7161, 10 Oct. 1991: There shall be collected charges on each cubic meter of timber cut in forestland, whether belonging to the first, second, third or fourth group, twenty-five percent (25%) of the actual F.O.B. market price based on species and grading.

Other common non-market input data is family labour. Instead of receiving a wage payment, a family labourer shares in the net income of the farm. In determining the price of labour the study makes use of the minimum legislated wage rate in the Philippines

Final farm level budget calculations were based on difference macroeconomic assumptions prevailing in the Philippines. Real interest rates (that is interest rate net of inflation) are the discount factors used to value future cash flow in current terms. As in most developing countries, capital markets in Philippines are fraught with imperfections. A discount rate[16] of 5.7% equal to inflation rate during data collection (September 2006) was chosen as the initial value for calculation to buffered profits from this condition. However, real private interest rates (at least for smallholders, if not for large corporations, which could secure subsidized credits) have been very high in real terms. Thus, it is argued that a private discount rate equal to inflation is a very low bound for the real cost of capital for smallholders. So, somewhat arbitrarily, discount rate two times (11.4%) the initial inflation rate was used for calculating net returns at social prices.

At some point, the analysis need to convert world export prices into domestic currency; this conversion requires an exchange rate. Exact exchange rate form U.S. dollar to Philippine peso (Php) was collected for the National Statistical Office of the Philippines at the time of analysis (Table 7.4).

Table 7.4. Prices and Macroeconomic assumptions used for PAM analysis

MACRO-ECONOMIC ASSUMPTIONS	**OBSERVATIONS / SOURCES**	**RATE**	**UNIT**
Social discount rate	= Inflation rate (%) in Sept 2006	5.7	%
Private discount rate	= 2x Inflation rate (%) in Sept 2006	11.4	%
Foreign exchange rate	U.S. $ to Php in Sept 2006	50.4	PhP
Commodity Policies			
Timber export tax	By RA No. 7161	25.0	%
Timber margin share	Transportation and transactions cost	25.0	%
Domestic subsidies	To tradable purchased inputs (i.e. seeds, fertilizer)	0.0	%
Commodity Prices			
Timber social price	Source: DENR (2006) published data	2,819.6	Php/m^3
Timber private price	= Social price – Export taxes – Margin share	1,409.8	Php/m^3
Maize social price	Source: FAOSTAT (2006)	6.6	Php/kg
Maize private price	= to social price	6.6	Php/kg
Urea social price	Source: FAOSTAT data (2006)	18.0	Php/kg
Urea private price	= to social price	18.0	Php/kg
TSP social price	Source: FAOSTAT data (2006)	16.0	Php/kg
TSP private price	= to social price	16.0	Php/kg
Cost of Labour			
Social wage	Minimum legislated wage rate	100.0	Php/ person-day
Private wage	= to social wage	100.0	Php/ person-day

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[16] *Discount rate* it is defined as the rate of interest that measures the opportunity cost of waiting to consume goods at a later time rather than consuming them today.

2.3. PAM calculations

The divergence between private and social profitability shows how polices and market imperfections affect the financial incentives face by smallholder farmers. As long as profitability calculation is concerned, the appropriate measure of profitability for long term investment is net present value (NPV), i.e. the present worth of benefit revenues less the present worth of the cost of tradable inputs and domestic factors of productions (Gittinger, 1982). Mathematically it is defined as:

$$\text{NPV} = \sum_{t=0}^{t=n} \frac{B_t - C_t}{(1+i)^t} \quad (1)$$

Where B_t is benefit at year t, C_t cost at year t, t is time denoting year and i is discount rate.

The NPV value provides indication of the profitability of the investment at the discount rate (interest rate) considered. The investment is profitable and viable when NPV is greater than or equal to zero. The NPV calculation for long period can be interpreted as the "*return to land*" for the selected land use activity, or "*return to labour*" that is the wage rate that sets the NPV equal to zero (Tomich *et al.,* 1998). Returns to labour were estimated as:

Returns to labour = Discounted net benefits to labour (2) / Discounted labour days (3)

$$(2) = \sum_{j=1}^{n} \left[\left(B_j - I_j \right) / \left(1 + r \right)^j \right]$$

B_j = benefits in year j, j = 1, 2,…, n

I_j = input costs in year j, j = 1, 2,…, n

$$(3) = \sum_{j=1}^{n} \left[WD_j / \left(1 + r \right)^j \right]$$

WD_j = Labour work-days

The wage rate that set the Net Present Value (NPV) for and activity or system to zero is used to establish the returns to labour. This measure answers the question, what is the maximum wage level (paid to family labour and hired labour alike) at which this land-use system will be profitable? The outcomes of this measure could be compared with wages earned in off-farm work or wages paid to agricultural labourers, to assess whether the system will be attractive to family members compared to off-farm work or whether it would justify hiring labour. Return to labour valued at private prices can thus be viewed as the primary indicator of profitability for smallholder's production incentives (Tomich *et al.,* 1998).

Two indicators are normally used to measure the labour requirements of a land-use system. First are the total person-days required to establish a system. The second one measures the labour requirements in person-days for the operational phase (defined as the period after positive cash flow begins). The two indicators have to be used together to calculate the total labour requirements of a given land-use system.

2.4. Sensitivity Analysis

Sensitivity analysis provides a way of assessing the impact of changed assumptions in estimating profitability. It can be applied to both private and social estimations. In principle, all social parameters can be subjected to sensitivity analysis. However, the social estimates of long run prices for output and the cost of capital are usually the most uncertain and hence receive the most attention in the sensitivity analysis (Monke and Pearson, 1989).

Elasticity is a concept in economics that measures the responsiveness of one variable in response to another variable. The best measure of this responsiveness is the proportional or percent change in the variables. This gives the most usable results for any type or range of data. Thus elasticity is the proportional (or percent) change in one variable relative to the proportional change in another variable. The general formula for elasticity is:

$$E = \text{percent change in } x \,/\, \text{percent change in } y \qquad (4)$$

In the study it was measured the responsiveness of each land use system in response to potential changes in the discount rate and output social prices (timber and maize). Lower proportional values on the elasticity for a particular land use it is interpreted as the system it is more robust to potential changes to those macroeconomic variables.

2.5. Economic risk

Risk analyses to account for the variability of benefits across land uses systems respond to changes in key parameters. Assess risk management at the level of livelihood strategies, based on economic risks of farm components use long term records of price fluctuations and extrapolated trends from these, to estimate the uncertainty in the net present value calculations. For this analysis each key parameter (i.e. discount rate and output prices) it was set a range of potential variability form half to two times of present social values and an unitary increment factor for randomized combination (Table 7.5). As a result a total number of 1,210 observations for each system analysed was plotted and fitted under a normal distribution function. Methodologically, the study illustrates a technique to evaluate both expected returns and the corresponding financial risks to obtain a complete, comparable profile of alternative systems. Negative profitability values will show cases expose to economic risk.

Table 7.5. Range of combination of key factors for economic risk assessment

FACTOR	RANGE	INCREMENT
Discount rate (%)	5.7 – 17.1	1.3
Maize price (Php kg^{-1})	3.3 – 13.3	1.0
Timber price (Php per m^{3})	1,410 – 5,640	422.0

3. Results

3.1. PAM results

3.1.1. Private and Social Profitability

The determination of profit actually received by farmers (returns to land and labour) is a straight forward and important initial result of the analysis. It shows which systems are currently competitive and how they are affected by actual price policies. PAM profitability results clearly shows that with the existing policies and macroeconomic conditions in Philippines tree farming systems provide very similar returns than maize monocropping scenarios from farmers´ perspective (private conditions). However, when profitability calculations are made with associate social prices tree intercrop systems will bear a considerable benefit with clear advantage to higher tree densities (Figure 7.1).

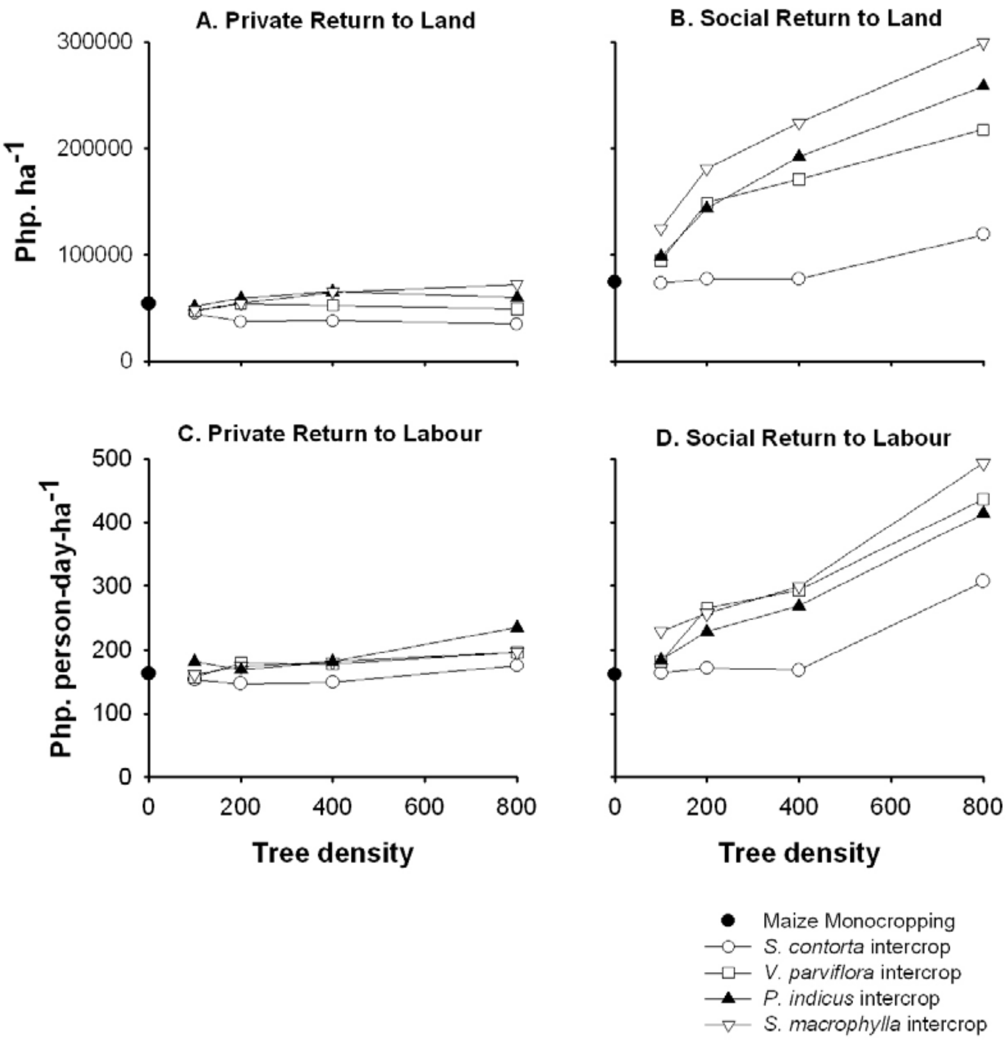

Figure 7.1. PAM social and private profitability results for each agricultural system

At the specific system level, return to land and labour show that not significant different among systems regardless the tree density and species under private conditions (Figure 7.1. A and C). Under social conditions (Figure 7.1. B and D), substantial differences were encountered among systems. Social benefits associate to tree intercrop systems should be attributed to the add value that timber produce in terms of transaction cost and charges collected.

3.1.2. Labour Requirements

Form the labour requirements there are two different ways of interpreting the results. From farmers' perspective, higher labour requirements associate to a specific production system reflects labour constrains that households have to face either form domestic resources or hiring external labourers. From the policy makers´ point of view, those systems reflect employment opportunities that can be created in rural areas.

In general PAM results in terms of total person days employed over time (for this study 15 years), suggest that tree intercrop system reduce labour requirement only at higher tree densities (800 trees ha^{-1}) (Figure 7.2). Thus, for labour constrain households intermediate tree densities (<400 ha-1) will not be an alternative management option if compare with monocropping scenarios.

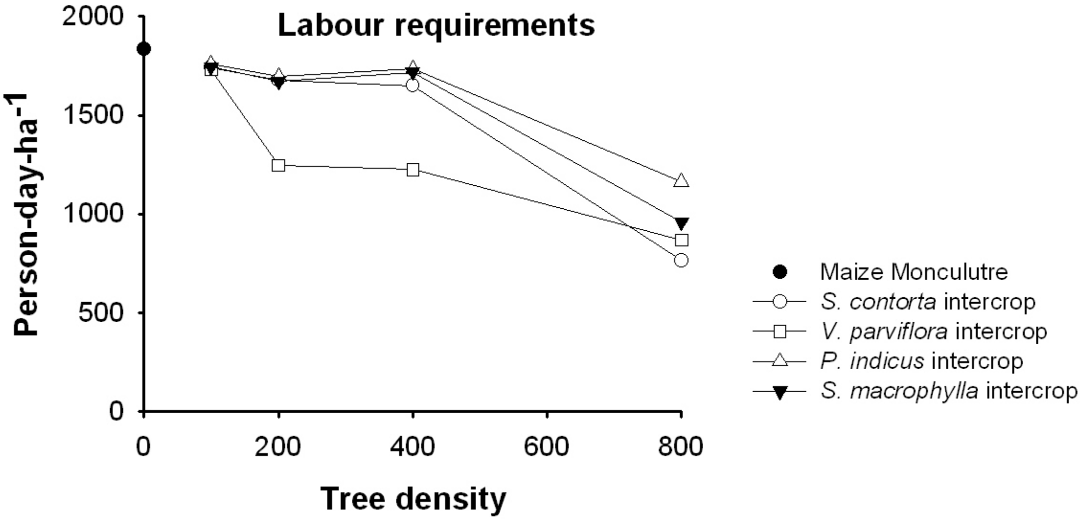

Figure 7.2. Labour requirements for each agricultural system

3.2. System respond to external variability

3.2.1. System respond to discount rate

Analyses results show that discount rate have lower effect on the crop component of the system than on the timber. Long rotation periods associate to trees (15 years for this study) involves a considerable uncertainty on the profits from the timber. As a result, intercrop systems are proportionally sensitive to the tree density (elasticity > 20%), while monocropping scenarios can be consider more robust (elasticity = 13 %) to the effect of discount rate (Figure 7.3.E).

At the level of individual systems, it can be seen that with a discount rate equal to inflation rate (5.7%) all intercrop systems are close but above the break even line (Figure 7.3.A). However, an increase of the rate two or three times higher makes that some of the system falls below the profitable threshold (Figure 7.3.B and C).

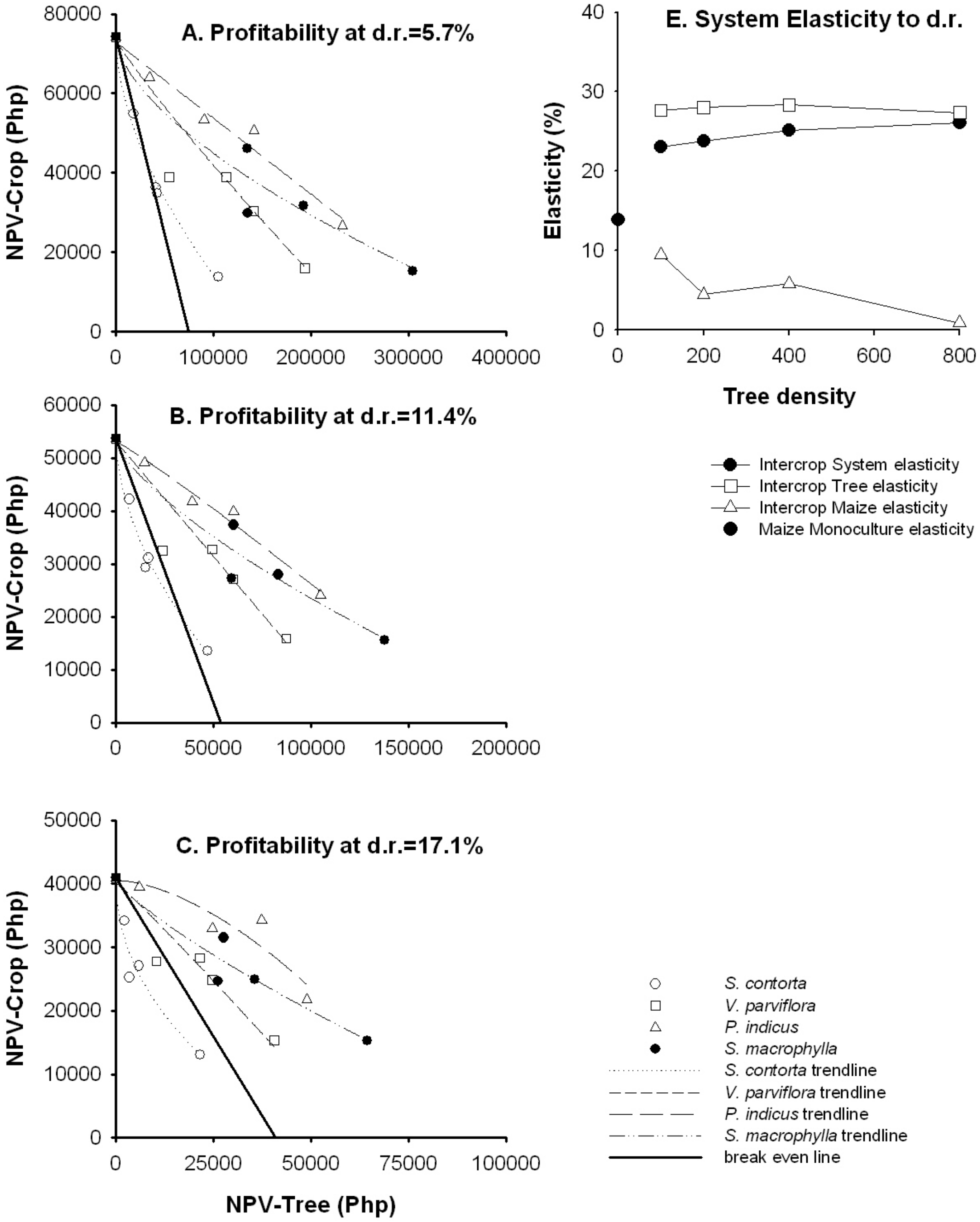

Figure 7.3. Systems elasticity to the effect of discount rate

3.2.2. System respond to output prices

Sensitivity analyses results show that monocropping systems are very sensitive to changes on prices (Figure 7.4.E). An elasticity value of 219% for maize monocropping scenarios to maize prices shows that this system is very expose to potential changes and thus, assuming an important potential risk form this decision. In this regard, intercrop systems are more robust to output prices and elasticity values will vary to 50 – 100% depending on the priority given either to the crop or the tree for a particular system.

This effect is particularly evidence at the individual system level. If the price of maize increases by two and timber price remain constant, all intercrop system that were above the break even line falls below the profitable level suggesting that under this conditions it doesn't exist any economic advantage for agroforestry. However, if the reverse case is analysed, maize price remains the same and timber price is increase by two, analyses results shows that all intercrop system will be a profitable alternative (Figure 7.4.B and C).

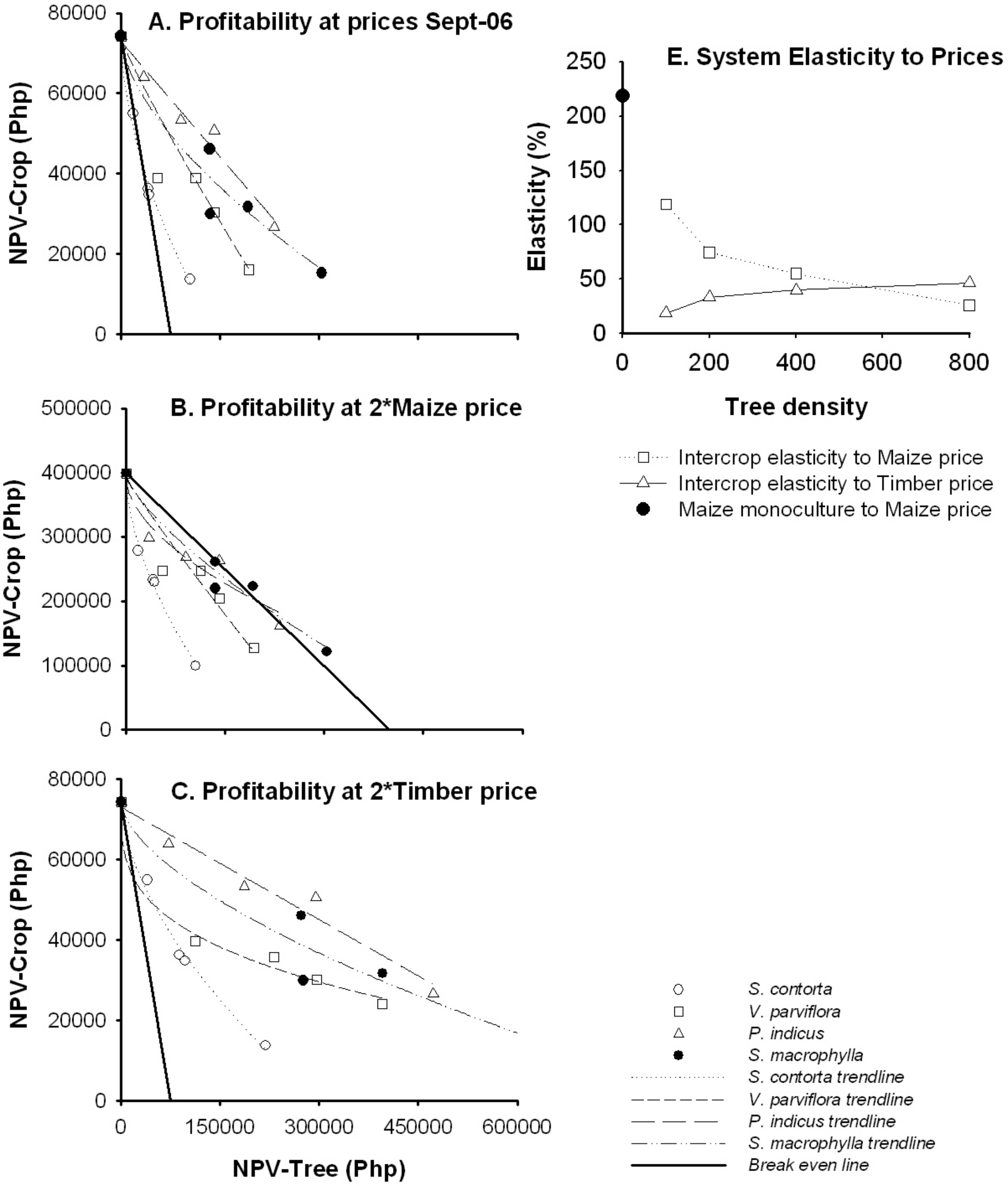

Figure 7.4. Systems elasticity to changes from output prices

3.3. Risk analysis

Risk results suggest that monocropping systems are expose to real economic risk while intercrop systems are buffered form this situation. The expected net incomes from the agroforestry systems were considerably higher than from monocultures and always maintain positive values (Figure 7.5.A), while from maize monocripping system 27% form total number of observations (1,210 cases) offered negative income values (Figure 7.5.B). It is important to remember that calculations for risk analysis were based on social conditions and that is the reason why timber is a key component in reducing farmer's financial risks.

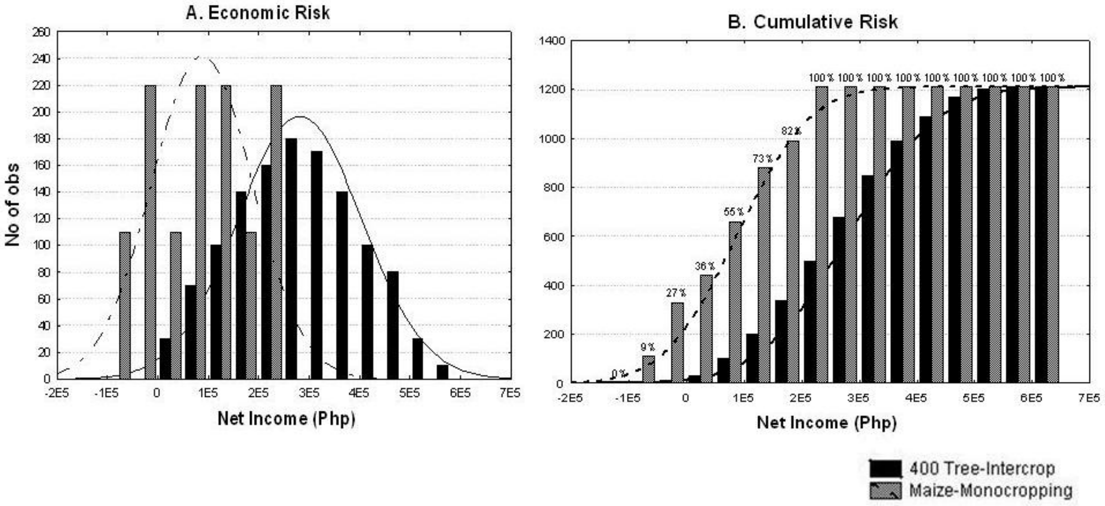

Figure 7.5. Economic Risk associate to monocropping and tree-intercrop systems

4. Discussions

Agroforestry system has long been recognized as a sound strategy to cope with price and crop yield variability, thus increasing farm income stability and lowering financial risk. However, results from this study limit the scope of that general assumption. From the profitability point of view, results confirm that the low economic incentive that farmers perceived form timber with the existing policy environment it might be stopping them from planting trees. PAM analysis revealed that with the existing farm gate price for timber, maize monocropping scenarios are as profitable as tree intercropping regardless the tree density and species planted. These results might explain why majority of smallholder farmers will not bother for innovating with alternative agroforestry systems and maintain their monoculture production systems.

However, the effects of divergences between private and social prices provide a significant social profit margin for tree intercropping scenarios attribute to market imperfections (inadequate development of institutions to provide competitive services and full information). Smallholders generally have weak market linkages and poor access to market information (Hammett, 1994; Arocena-Francisco *et al.*, 1999). The existence of accessible market for tree products is vital for the development of tree farming systems (Scherr, 1995; 1999; Landell-Mills, 2002). For example, Pedro (2002) found that tree farming in the Philippines was more profitable than annual crop system, but the uncertain marketing conditions deterred tree planting. The dynamics of tree product supply, market demand, and marketing channels at the smallholder level are poorly understood by farmers and researchers alike (van Noodwijk *et al.*, 2007). Constraints on the contribution of agroforestry to sustainable forest management can be overcome, if public domain information access on market conditions improves. By understanding market linkages and interactions, it should be possible, at relatively low cost, to improve smallholder farmers´ livelihoods by focusing their agroforestry production towards market opportunities (Roshetko *et al.*, 2004).

All divergences between private and social prices of tradable output that cannot be attributing to market imperfection are caused by distorting policies. Particularly in the case of the Philippines, timber export charges and high transaction cost could endow with an important financial social benefit for planting timber trees. The Philippine government should seized this economic opportunity by promoting tree planting activities, either by standard reforestation or agroforestration[17] programs. However, incentive schemes to encourage farmers´ participation in reforestation activities have not been able to draw a genuine interest on tree planting. Consequently, most plantations have been abandoned once payments and compensations were terminated (Bertomeu, 2004). The failure of subsidy-driven reforestation and the success of spontaneous tree growing on farms suggest that the goal of profitable tree production is in itself meditated by other objectives (Scherr, 1999). For example, price incentives at farmer level for higher quality timber products should be a good strategy to conduct farmers towards productions systems with real market opportunities.

At macroeconomic level the primary concern is how to modify key factors that can stimulate the forestry sector contributions to the overall national economy. Inflation is caused principally by macroeconomic policy assisted by inflation abroad that caused the prices of import and export to rise. If the government chooses to have a fixed-exchange rate regime, the exchange rate will be changed only through discrete policy decisions, not because of market forces. When governments create inflation and then choose not to depreciate the nominal value of their currencies (by changing the exchange rate so that more units of domestic currency are required for each unit of foreign currency), profits are squeezed in agricultural systems that produce tradable commodities. Governments that consider their short-term needs for foreign exchange to be inelastic have an interest in examining the direct exchange burden of particular agricultural systems. Because long-run benefits are hard to sell politically in any society, macroeconomic reform typically occurs only when a country has exhausted all delaying options. Hence, it is much easier to steer a developing economy off its best macroeconomic policy path to long-run development than it is to make the painful corrections usually needed to return to that path. This unfortunate reality causes special difficulties for agriculture and rural-based small industry in countries with distorted macroeconomic policy (Monke and Pearson, 1989).

Nevertheless, recent economic analyses are beginning to indicate what kind of policy reforms may be necessary to improve the incentives for better land management in developing countries. Very generally, it appear that policy reforms that reduce price distortions, promote efficient operation of rural financial markets, and make property rights enforceable should reinforce these incentives (Coxhead, 1997). In some countries, there may be a "win-win" situation between general macroeconomic and sectoral reforms and improved land management. In the Philippines and Indonesia, it was found that reducing import tariffs and export taxes may also reduce the rate of upland degradation (Pearce *et al.*, 1990; Coxhead and Jayasuriya, 1995).

Additionally, many national policies which are intended to conserve and protect natural resources discourage the cultivation – and thus conservation – of native species by restricting the utilization or trade (Tomich and Lewis, 2001). Moreover, taxation schemes that classify smallholder-grow tree products, as products from natural forests, significantly reduce the profitability of these smallholder tree farming systems. Inappropriate interpretation and enforcement of national policies by local officials leads to further confusion. In response to these policies, or their perceptions of

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[17] As defined by Roshetko *el al.* (2007) Agroforestation refers to the establishment of smallholder agroforestry systems, and implies land rehabilitation through the establishment of a tree-based system and intensification of land management.

these policies, many smallholders choose not to cultivate native trees on a large scale. Smallholders may actively remove the natural regeneration of native species because the resultant trees can not be 'utilized' (ITTO, 2001). Selective deregulation of trade in agroforestry timber species is an attractive policy option that can stimulate equitable economic growth while protecting the environment (Tomich and Lewis, 2001).

Generally, tree farming systems are considered as less labour-demanding than annual cropping and therefore, a shortage of family labour usually motivates farmers to plant trees. Results from this study show that tree intercrop system will be an effective household strategy to reduce labour requirements only if primary attention is given to the tree instead to the food crop. Moreover, when family labour is engaged in off-farm employment, farmers are more likely to invest in tree planting as a low-labour land use strategy (Dewees, 1992; Tacher *et al.,* 1996). At the local level, creation of off-farm job opportunities for younger generations might be one of the most important concerns for rural communities. Stimulating wood industry in rural-based communities could have a double purpose of bringing job opportunities and promote tree farming systems with market linkages.

Interpretation of the results of sensitivity analysis is somewhat arbitrary. Whether elasticity values are large or breakeven are very different from initial values depends on the quality of the initial estimations and the degree of potential change in the variables (Pearson *et al.,* 2004). However, results show that the timber component was a key factor in increasing the overall system robustness from external variability and thus reducing financial risk.

5. Conclusions

- In the Philippines, agroforestry systems offer better financial prospect although with the existing policies and market conditions these benefits are not yet perceived by individual farmers.
- Particularly, timber export charges and high transaction cost endow with an important financial social benefit for planting timber trees.
- The Philippine government should seized this economic opportunity by promoting tree planting activities, either by standard reforestation or agroforestration programs.
- Low economic incentive that farmers perceived from timber with the existing situation might be stopping them from planting trees and maintain their agricultural monoculture systems.
- Taxation schemes that classify smallholder-grow tree products, as products from natural forests, significantly reduce the profitability of these smallholder tree farming systems.
- Tree intercrop system is an effective household strategy to reduce labour requirements only if primary attention is given to the tree instead to the food crop.
- Monocropping systems are expose to real economic risk while tree intercrop systems are buffered form external variability.
- If a real interest form Philippine government to introduce tress on farms for recovering degraded landscapes and improve rural livelihoods, specific changes on existing policies for stimulating wood industry might be prior needed.

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8. WHAT IS NEEDED TO FACILITATE THE RECOVERING PHASE THAT IS LIKELY TO TAKE PLACE IN THE PHILIPPINES?

Economic and policy conditions that might be prior necessary

1. Economic conditions

Forest transition theory as discussed in chapter 1 suggests that there are strong forces which make forested areas lose a substantial part of their forest cover, before the reverse process starts. This can be seen as a synthesis of the historical experience, and, as such, incorporates fundamental demographic, economical and political forces (Angelsen, 2007). It also explains the time lags involved in getting a sufficient part of stakeholders to realize that they have or are getting a problem and why it is easier to mobilize effort for 'rehabilitation' than it is to get resources for 'avoided degradation', even though in theory everybody knows prevention is better and less costly than cure (van Noordwijk, 2005a).

Rudel *et al.* (2005) suggested two possible pathways for advanced forest transition. One is the "economic development route", where the agricultural population declines as industrialisation and urban migration proceed, and abandoned agricultural land is spontaneously reforested. The other, is the "forest scarcity pathway", where scarcity of forest products drives up price and stimulates tree planting. Rudel *et al*. (2005) emphasized that overlaps can occur between these two types, but the implication is that different causes apply to the two pathways. One could be labelled as industrialisation, economic development or modernisation, while the other has a more directly economic cause in terms of a market response to trends in demand and supply of forest products.

In the first stage of industrialization, pollution grows rapidly because high priority is given to increase material output, and people are more interested in jobs and income than in clean air and water (Dasgupta *et al*., 2002). The rapid growth inevitably results in greater use of natural resources and emission of pollutants, which in turn put more pressure on environment (Dinda 2004). Therefore the relevant question is: can economic growth be part of the solution rather than the cause of environmental problem?

Economic growth linked to creation of employment in urban and non-agricultural sectors has to be the main way out for the next generation of rural people across the tropics (Tomich *et al*., 1995) (Photo 8.1). This requires both the provision of affordable high quality food and the provision of clean water and other environmental services. Agricultural intensification has traditionally supported the "affordable food" part of this relationship, but also caused concern on the environmental service side. The alternative development pathway based on imported food while conserving the local environment is only feasible for well-endowed countries with large oil or mineral reserves, which is not the case of the Philippines, so the agricultural and forestry sector has to be the basis for development (van Noordwijk *et al*., 2006b).

Photo 8.1. Next generation of upland farmers in the Philippines

A statistical analysis of 53 tropical countries has attempted to explain the aggregate economic determinants of tropical deforestation (Barbier and Burgers, 2001). The result indicates the increased population density increased forest clearance, whereas rising income per capita and agricultural yields reduce the demand for forest conversion. The latter effects suggest that as countries develop economically and the productivity of their existing agricultural land improves, there is less pressure for deforestation.

The Millennium Ecosystem Assessment (2005) raises two more important questions:

- Is it possible to reduce the lost of forest and maintaining their functions until the development phase where the forest is emerging as the “best choice” land cover?
- Can intermediate land uses (agroforestry) facilitate the economic transformation that is likely to take place?

The results of FAO´s Global Forest Resources Assessment 2005 (FAO, 2006) indicate that the net loss of forest in Asia that persisted for many decades has now been halted. Form 2000 to 2005, there was an annual net gain averaging just over 1 M ha, to which China, India and Viet Nam were major contributors. Asia is the first continent to display a transition form net deforestation to net reforestation since systematic collation of data of global forest resources began in the 20th century (Mather, 2006). Forest expansions takes two main forms, the establishment of plantations and the spontaneous reforestation of agricultural land abandoned or other land uses.

The period of high deforestation (forest frontier stage) is driven by an initial increase in the agricultural land rent, typically by new roads that increase demand and prices for agricultural commodities and open up for inflow of labour and capital. Self-reinforcing mechanisms further stimulate and maintain high rates of deforestation. The stabilization of forest cover is in most cases brought about by two forces: economic development, which increases the opportunity costs of labour (reduced agricultural rent), and higher demand and prices for forest products (increased forest rent) (Angelsen, 2007).

A major problem with attempts at reducing the agricultural rent during the forest frontier stage is that they also tend to have adverse effects on rural income, e.g., reducing market access, constraining access to capital. The mechanisms that during the next stage help to stabilize the forest cover are, on the other hand, more compatible with the aim of poverty reduction. Higher rural wages and higher prices for forest products tend to produce win-win outcomes. Thus a more acceptable strategy is to speed up the forest transition by stimulating these stabilizing forces (Angelsen, 2007).

According to Thorbecke and Nissanke (2006) countries which have not yet reached the critical development threshold need (i) to invest on in agricultural in to reach the takeoff point to allow the structural transformation of their economies to proceed; and (ii) to strengthen institutions of social protection. Among the many institutional issues, the human resource of the extension organization is one of the most important things to discuss because it determines the sustainability of any program. Within the decentralization era, it is crucial to strengthen the linkages between community organizations, technical agencies (national and international), commercial sector and government agencies to integrate information of local objectives, technical knowledge, market needs and government policies as a means of identifying mutual goals and conflicts management strategies (Roshetko *et al.*, 2007a).

Agroforestry is obviously a part of the whole spectrum of using land sensibly with potential for increasing both productivity and sustainability, but these potentials must not be taken for granted (Huxley, 1999). Evidences from this thesis suggest that enthusiasm should be temper about what agroforestry might achieve. This intermediate land use strategy is based on the overall assumption that, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels (Roshetko *et al.*, 2007a). These issues involve many actors and aspects, and thus can benefit from many disciplinary perspectives. Hence, it is critical to better understand each others perspectives and look for solutions that can be acceptable to all, while being perfect to none (van Noordwijk *et al.*, 2001).

In many agroforestry projects, adoption rates are low, and where the adoption was successful, the farmers often adapted the system to suit their requirements. There are significant constrains on farmers´ willingness to adopt agroforestry systems (Current *et al.*, 1995). Systems such as alley cropping are generally very labour-intensive, whereas fallow and some perennial systems require large land holding. Farmers without well-defined land rights do not have the incentive to invest in agroforestry systems and in many countries tree-harvesting laws and regulations are significant barriers to adoption. The riskiness of the returns is a particular problem for agroforestry systems, with fluctuations in tree product yield and price especially influencing the profitability of intercropped systems. Other market and institutional failures, such as distorted market prices for inputs and outputs, imperfect competition, lack of information about markets channels etc., can all affect the farmer’s perception of the cost and benefits of adopting agroforestry. Current *et al.* (1995) concluded that “poorer farmers may find agroforestry profitable, but their rate and scale or adoption is often constrained by limited land, labour, and capital resources and their need to ensure food security and reduce risks”.

New initiatives in agroforestry are seeking to integrate into tropical farming systems native trees species whose products have traditionally been gathered from natural forest (Leakey and Simons, 1998). This is being done in order to provide marketable products from farms that will generate cash for resource-poor rural households. This poverty-alleviating agroforestry strategy is at the same time linked to one in which perennial, biologically diverse and complex mature stage agroecosystems are developed as sustainable alternatives to slash-and-burn agriculture (Huxley, 1999). The domestication of these native timber species may provide alternative species for industrial wood production that are better adapted to the local environment and provide a wider range of quality hardwood to broaden the forestry production base (Haggar *et al.*, 1998).

2. Policy determinants

Governance is the second variable with which forest trends have frequently been linked. At the global level, forest trends have been positively correlated with quality of governance (Deacon, 1994; Didia, 1997; Angelsen, 2007). Policy analysis should help to understand the basic forces at work and thereby design appropriate policy measures according to the stage in the transition and the forces at work. The political development process in the countries and regions concerned will be determinant to facilitate the transformation that is likely to take place. For instance, Mather (2006) recognizes that strong states, even if not democratic, are almost by definition better able to bring about forest transitions than their weaker counterparts. Those countries lying between authoritarian and fully-fledged democracies (as the case of the Philippines) may find it particularly difficult to do so.

According to van Noordwijk (2005b) three ways are open to governments of developing countries to deal with this issues: 1) allocating substantial tracks of state-controlled land to "concessionaries" for development of a tree plantation industry, with a benefit sharing between the concessionaire and the state, 2) stimulating targeted tree planting activities in the context of a "national reforestation" program, and 3) removal of constraints to spontaneous smallholder adoption of tree-based farming systems as part of their multifunctional landscapes.

Form the first approach, economic theory predicts that increased scarcity of wood (once access to the remaining forest stocks is effectively constrained) will enhance the price and stimulate production. The primary policy concern in this approach relay over the capacity market mechanism to respond the scarcity of essential land functions (i.e. agricultural production, wood supply) and increase of the relative price of the scarcest products and services. The main challenge that politicians will have to deal with this market driven approach are based on time-lags (tree planting requires of future rather than current values), exclusion on smallholder farmer, restricted assess to land, inequity access to resources, assume high environmental and economic risk from monospecific plantations and incomplete information and knowledge (Photo 8.2). Additionally, if economic growth leads to an increase in income inequality, the poor may benefit only slightly or, in some instances, actually be hurt by this market driven approach (Thorbecke and Nissanke, 2006).

The second approach is aimed at rehabilitating degraded and public lands through government sponsored tree plantations of various kinds, but with non-use value of trees and forest from farmers' perspectives. The main political concern here is the provision of environmental services in regulating water and air quality and conserving biodiversity. The provision of subsidies is an important requirement of this approach although does not necessarily assure any success, because in many cases land uses revert to former practices once the subsidies eventually end (Armstrong, 1992). Moreover, because this approach has not address the growing market demand of wood products, experiences were usually limit the scale and geographical coverage of such investments.

Photo 8.2. Sawn-mill plant to cover local demand of timber in Leyte (Central Philippines)

The third approach, relates to remove policy constrains that limit independent and small or medium scale farmers to include and use trees within their land resources. The primary policy concern is to increase tree contribution towards economic growth, environmental benefits and to reduce and minimize national unemployment and poverty (pro-growth, pro-environment, and pro-poor). The main challenge to face through this approach will be restrict and control open-access to remaining forest, land tenure assurance, renew administrative procedures for tree planting, link smallholders to markets with quality timber products and support these initiatives through reward mechanisms for environmental services (Table 8.1).

Table 8.1. Summary of three possible policy approaches to promote tree planting activities

APPROACH	POLICY CONCERN	CHALLENGES TO FACE
Market Driven	Development of tree plantation industry	- Excluded smallholder farmers - Time-lags - Restricted assess to land - Incomplete market information - Assume high risk - Timber product quality
National Reforestation	Improve environmental conditions	- Provision of subsidies - Non-use value of trees for farmers' - Not linked with market demand - Limit to scale and geographical coverage of investments
Spontaneous Agroforestation	Remove policy constrains for tree farming systems	- Restrict and control open-access to remaining forest - Land tenure assurance - Renew administrative procedures for tree planting - Link smallholders to markets with quality products - Reward mechanisms for environmental

Nowadays, many developing countries are undergoing major economic and political structural reforms, but it is not always evident that these reforms will succeed in removing some of the critical constrains affecting strategic development. Hence, policymakers need to design and implement an active development strategy not only to benefit from, but also to help counteract the negative effects of the immutable forces of current global organization. It is not enough for governments to assume an active role on regulating their economies while deliberately avoid domestic development policies. As Kanbur (1998) notes, the central policy dilemma is “how to take advantage of the undoubted opportunities that integration into the world economy affords for rapid growth, while managing the attendant risks for domestic income distribution in its different dimensions”. This requires a much better grasp of the concept of *pro-poor* development than what we presently hold.

Rules and policies associated with land management are rapidly evolving, and need to continue to evolve, if the promises of agroforestry to alleviate poverty and mitigate environmental degradation are to be met. Development of efficient and effective reward structures for environmental services seems to be a viable way to achieve environment plus development goals (Tomich *et al*., 1998; Landell-Mills and Porras, 2002; Murdiyarso e*t al*., 2002; van Noordwijk *et al*., 2006a). However, these efforts are still in their infancy and at too small scale to have any significant impact on regional or global patterns. With averted deforestation now being brought in the climate change negotiations, this might change in the future (Angelsen, 2007).

The possibility of “reward for carbon storage” can apply to smallholder tree planting in fine-grained landscape mosaics (Leimora *et al*., 2006; Suyanto *et al*., 2007). The ability to simultaneously address smallholders´ livelihood needs and store large amount of carbon make smallholder timber-based agroforestry systems a viable project prototype under the Clean Development Mechanism (CDM) of the Kyoto Protocol (Roshetko *et al*., 2007b). However, existing certification schemes with their high transaction costs provide strongly positive economies of scale that put smallholder producers at a disadvantage (van Noordwijk *et al*., 2007). The subsequent challenge is thus to develop mechanisms that reduce these costs: (a) the cost associated with information (i.e. technology, markets) more accessible to multiple clients; (b) facilitating and enforcing smallholder agreements and (c) designing feasible monitoring systems.

Finally, in many development countries policy reform will have to be complemented by investments in key infrastructural services. Several have been mentioned already: the ability of rural investment, conservation and general extension services, land tenure and titling services and other land improvements for existing smallholder land. However, other services may also be important. For example, in most rural areas there needs to be a general development of adequate post-harvest and marketing facilities targeted as smallholder production. In frontier areas, there is a need not only to increase credit and extension services to settlers, but also more basic services such as improved community, education and health care conditions (Barbier, 1997) (Photo 8.3).

Photo 8.3. Basic services of education and health need to be cover for a proper development

3. Synthesis of results

As seen form above discussion, existing policies and economic rules for land sustainable management set the boundaries conditions for agroforestry. van Noordwijk *et al.*, (2007) elaborated a check list of ten hypotheses with partial evidence that is currently constraining for farmer driven agroforestation phase of the landscape. The results presented in the preceding chapters can now be compared with the list of ten hypotheses on smallholder timber production in agroforestry systems in Table 8.2.

Table 8.2. Ten hypotheses on smallholder timber production in agroforestry systems (adapted form van Noordwijk *et al.*, 2007) and a synthesis with partial evidence from this thesis

HYPOTHESIS	PARTIAL EVIDENCE IN THIS THESIS
1. Timber-based agroforestry systems has no chance as long as open-access forests still provide for the resource below economic replacement cost	Charter 3 statically analysis confirm this idea that farmers living in boundaries areas to forest will be reluctant to plant timber trees
2. Lack of land tenure, physical or economic assess to landholding resources will keep farmers out from long term production investments	Chapter 3 results verify this idea showing that all landholding variables have the strongest effect on farmers´ intention to plant trees
3. Rules aimed at restricting illegal logging as suppliers of the demand for wood provide strong negative incentives for the smallholder timber production that would provide a long term alternative to illegal logging	Every farmer interview during data collection expressed that long and tedious administrative procedures relating to cultivation, processing, transport and marketing disincentive then to engage on tree farming
4. Matching tree species to appropriate site conditions is crucial for sound agroforestry production	Chapter 4 results suggest that the high variation of tree performance that could not be explained implicates that farmers take considerable risk in planting trees on the basis of current 'scientific' knowledge
5. Short rotation forestry with the existing narrow array of exotic species carries high biophysical and economic risk	Chapter 5 results shows that alternative native species might provide similar benefits than some exotic and thus, should first be considered as a starting point in any tree planting programme
6. Most smallholder agroforestry systems are characterized by limited proactive management and planning with a low quality output product as a result.	Chapter 6 results show that there is a trade-off between system components, which will be determinant when considering the final choice of tree-crop combination and planting design
7. Smallholders generally have weak market linkages because the quality of their products doesn't reach the market standards	Chapter 6 reveal that by better understanding smallholder production systems, it should be possible, at relatively low cost, to improve farmers´ livelihood by focussing their agroforestry products towards market opportunities
8. Current agricultural policies provide positive inventive (net transfer) for food crop production and negative ones on timber production	Chapter 7 PAM analysis results suggest that although timber-based systems indeed offer better financial social prospect than crop monoculture with the existing policies this benefits are not yet perceived by farmers
9. Timber-based agroforestry systems provide superior returns to labour in an intensification phase when labour shifts from rural to urban jobs and provide a security net and retirement saving component of livelihood strategy	Chapter 7 profitability results show that under ideal social conditions (market imperfection and policy distortion are excluded) timber-based systems may provide an alternative way for less depending on food production and rural links
10. Trees in a landscape can have positive environmental effects or "provide environmental services"	In the absence of a "reward mechanism" the presence or absence of these services is left of policy decision maker to whom off-farm benefits and cost are externalities.

Overall the five specific hypothesis and objectives presented in Chapter 2 were tested and results presented in this thesis in the form of individual chapters. The consolidation of each result lead to synthesize in this final chapter, what are the policy and economic determinant needed to facilitate the forest transition that is likely to take place in the Philippines.

Initially this thesis was designed to gain a better understanding of the current land used decisions that lead to rapid conversion of natural forest, and the slow and difficult process of land recovering through sustainable land use practices. In this regard the overall objective of the study (*close knowledge gaps and provide a better understanding of smallholder timber-based agroforestry systems using native species)* was achieved through answering key initial questions on each chapter. However some limitations characteristic of the nature of this type of work (e.g. time and resource restrictions) didn't allow getting deeper knowledge in some other important issues to cover a holistic perspective on the tree domestication process.

However, through the experience gained with this study it can be confidently verify the overall study hypothesis and conclude that using native timber trees within smallholder production systems is a clear alternative to recover degraded landscapes in the Philippines because it result in an land use that is both sustainable and productive. But to start this rehabilitation phase it is first needed a deep social, economical and political change at all levels and scales.

4. Final conclusions

- Timber-based agroforestry systems has no chance as long as open-access forests still provide for the resource below economic replacement cost and land tenure is not secured for smallholder farmers.
- Locally accepted native timber species might provide similar benefits than some exotic and thus, should be first considered as a starting point in any tree planting programme.
- Agroforestry systems are characterized because there is always a trade-off between system components, which will be determinant when considering the final choice of tree-crop combination and planting design.
- Better understanding smallholder of production systems it is need to improve farmers´ livelihood by focussing their products towards market opportunities.
- Current agricultural policies provide positive inventive for food crop production and negative ones on timber production
- Under ideal social conditions (market imperfection and policy distortion are excluded) timber-based systems may provide an alternative way for less depending on food production and rural links
- Thus, agroforestry systems with native timber trees is obviously a part of the whole spectrum of using land sensibly with potential for increasing both productivity and sustainability, but these potentials must not be taken for granted.

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ANNEX 1: INTERVIEW SCHEDULE FOR FARMERS

Place of interview: ______ Date: _________Name of the respondent: _________________

1. Knowledge on Trees

Do you have any experience in tree farming (both indigenous and exotics will be considered): ________________, No. of years:________________

What is your main interest in growing / maintaining / using trees?

Main problems in growing trees:___________________________________

Have you attended any training/ seminar related to tree cultivation and management?

Focus of training/seminar	**Year**	**Place**	**Organizer**

Major source of information about trees/ tree related information:________________

Is there any tree nursery in the area: _______, if yes, where?___________________

Trees species raised: ____

Purpose of raising tree seedlings: ____

Can you avail seedlings and what are the arrangements?:_____________________

Sources of seeds/germplasm:____

Do you participate in any of these nurseries: _______, if yes, how?_____________

Specifics of trees used / known (Note: always specify "others"!)

A) Indigenous tree species known	**B) Where is this species found?**	**C) If not existing when last found?**	**D) Which ones have you planted?**	**E) No. of trees or Area covered on farm**	**F) Planting or distribution system**	**G) MAIN USES**	**I) Kind of materials used for propagation**

Tree products

TREE PRODUCT	**Tree species**	**Disposal**	**Market price**

Which of the species you prefer most? (Rank!)

NAME	**Why?**	**Preferred species characteristic of**	**Constrains to growing on-farm**
1.			

Indigenous and exotic tree species compared

	Indigenous tree species	Exotic tree species
Advantages (Pros)		
Disadvantages (Constraints)		

How do you manage/maintain trees?____

How do you harvest trees?____

Age or size of trees at harvest:____

What tree processing methods and establishments are available in the area?

If you process yourself, which species and how? _______________________________

Involvement in past and present activities in forestry (reforestation, tree cultivation, silvicultural practices):____

Any policies, programs, rules or regulations (e.g. existing land tenure system) that influence your decision in cultivating trees?, and how do they influence you?

Please name those knowledgeable about indigenous trees in your area (barangay and municipality)

Name	**Address**	**Position / Job**

2. General Household Information

Position in the HH:_____________________________

Age:___________ 3. Sex:______ 4. Educational attainment:_____________________

Civil Status:_______________ 6. Religion:_____________________________________

No of years living in the barangay:________________

Migrated to area (yes or no):_______ If yes: when?_____________, from where? __________________________, and why?______________________________________

No of household members.:___________ No. of dependents:________________

No. of household members working off / non farm:_____________

No. of household members working on own farm:_______________

Housing, type and materials (observed): _____________________________________

No. of years in farming:______________

Total area owned (ha):__________________, tenanted/rented:__________________

No. of parcels:__________________

How does land tenure influence your decision making in farming?: _______________

Area of sloping land (ha): __, level land:_______,area of low-land rice:___________

Area under annual crops:______________

major crops – 1st cropping: ____

major crops – 2nd cropping: ____

Area under perennial crops: ____________, major crops: _______________________

Area under agroforestry: ______________, major species_______________________

Area under tree plantation: ___________, major species:_____________________

Do you apply any inputs? Fertilizer: ________If yes, where applied?_____________

other inputs:____

Sources of income	Average income per year
a.________________________________	______________________________
b.________________________________	______________________________
c.________________________________	______________________________
d.________________________________	______________________________

What percentage of the household income is derived from tree farming or sales of tree products? ____

Distance to the nearest market:___________

Accessibility (specify!):____

Do you practice kaingin on your farm? (Describe practice!) ____________________

Have you observed soil erosion in your farm?_________, if yes, what are the signs?

Any soil conservation measures applied in your farm? (Describe practice!)

If there is, since when?________________

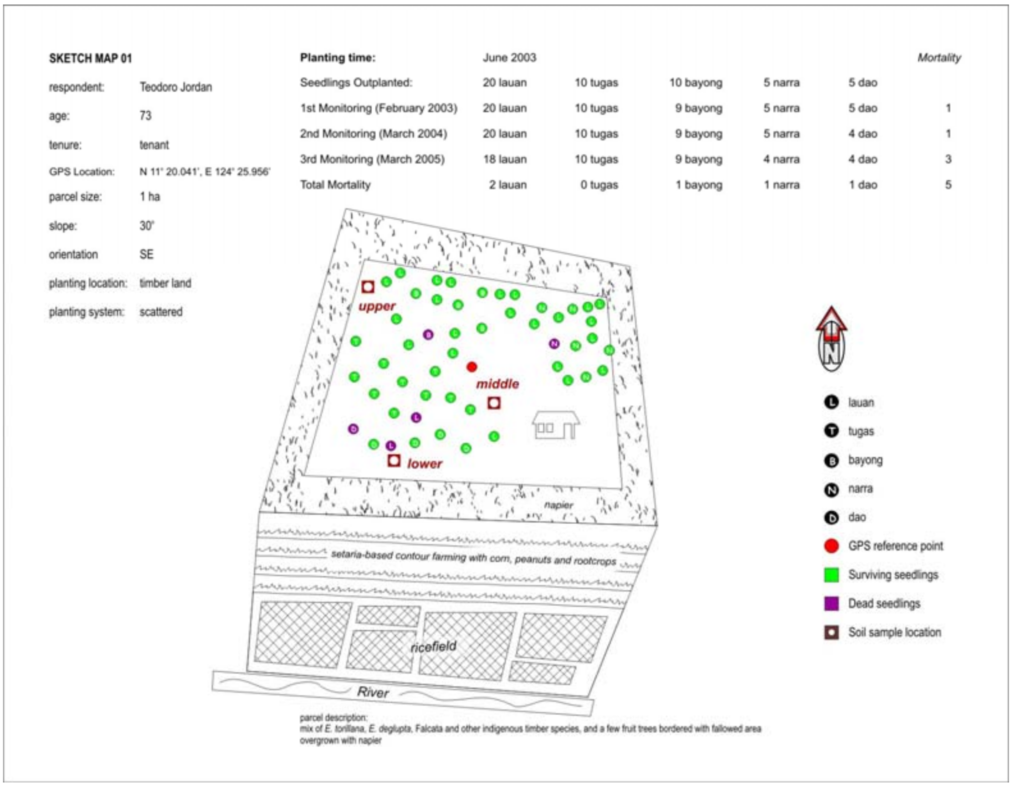
Major source of farming related information:

Membership in any local organizations:

Name and nature of organization	Position held

NOTE: Attach any other information that you feel relevant and is not already covered in the questionnaire, especially on indigenous trees.

ANNEX 2: FARMERS FIELDS SKETCH MAPS



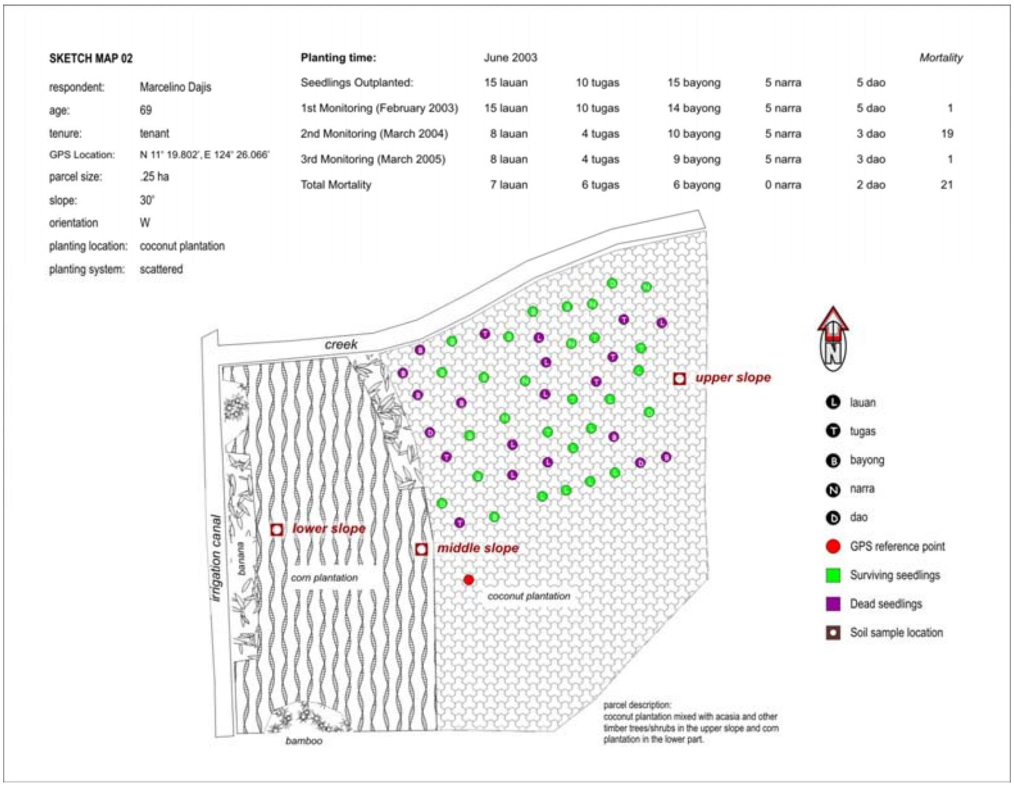
SKETCH MAP 01

respondent:	Teodoro Jordan
age:	73
tenure:	tenant
GPS Location:	N 11° 20.041', E 124° 25.956'
parcel size:	1 ha
slope:	30°
orientation	SE
planting location:	timber land
planting system:	scattered

Planting time:	June 2003					*Mortality*
Seedlings Outplanted:	20 lauan	10 tugas	10 bayong	5 narra	5 dao	
1st Monitoring (February 2003)	20 lauan	10 tugas	9 bayong	5 narra	5 dao	1
2nd Monitoring (March 2004)	20 lauan	10 tugas	9 bayong	5 narra	4 dao	1
3rd Monitoring (March 2005)	18 lauan	10 tugas	9 bayong	4 narra	4 dao	3
Total Mortality	2 lauan	0 tugas	1 bayong	1 narra	1 dao	5

parcel description:
mix of *E. torillana*, *E. deglupta*, Falcata and other indigenous timber species, and a few fruit trees bordered with fallowed area overgrown with napier

Figure 1. Teodoro Jordan's farm



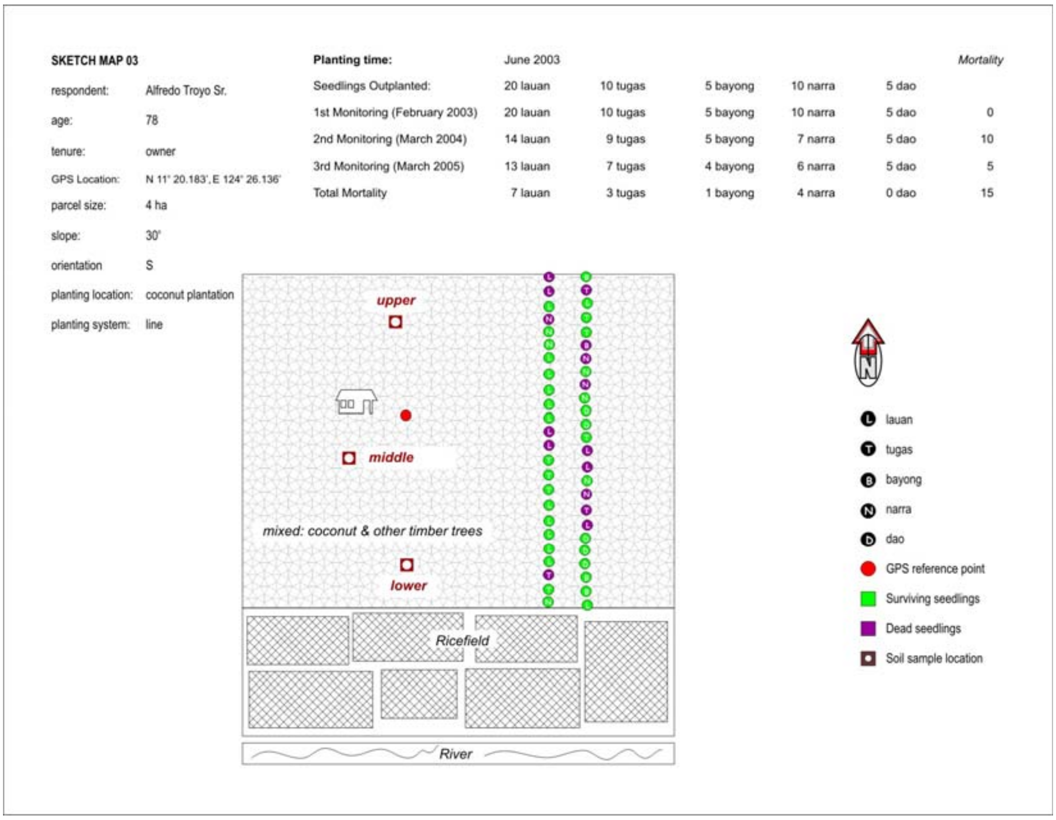
SKETCH MAP 02

respondent:	Marcelino Dajis
age:	69
tenure:	tenant
GPS Location:	N 11° 19.802', E 124° 26.066'
parcel size:	.25 ha
slope:	30°
orientation	W
planting location:	coconut plantation
planting system:	scattered

Planting time:	June 2003					*Mortality*
Seedlings Outplanted:	15 lauan	10 tugas	15 bayong	5 narra	5 dao	
1st Monitoring (February 2003)	15 lauan	10 tugas	14 bayong	5 narra	5 dao	1
2nd Monitoring (March 2004)	8 lauan	4 tugas	10 bayong	5 narra	3 dao	19
3rd Monitoring (March 2005)	8 lauan	4 tugas	9 bayong	5 narra	3 dao	1
Total Mortality	7 lauan	6 tugas	6 bayong	0 narra	2 dao	21

parcel description:
coconut plantation mixed with acasia and other timber trees/shrubs in the upper slope and corn plantation in the lower part.

Figure 2. Marcelino Dajis´ farm

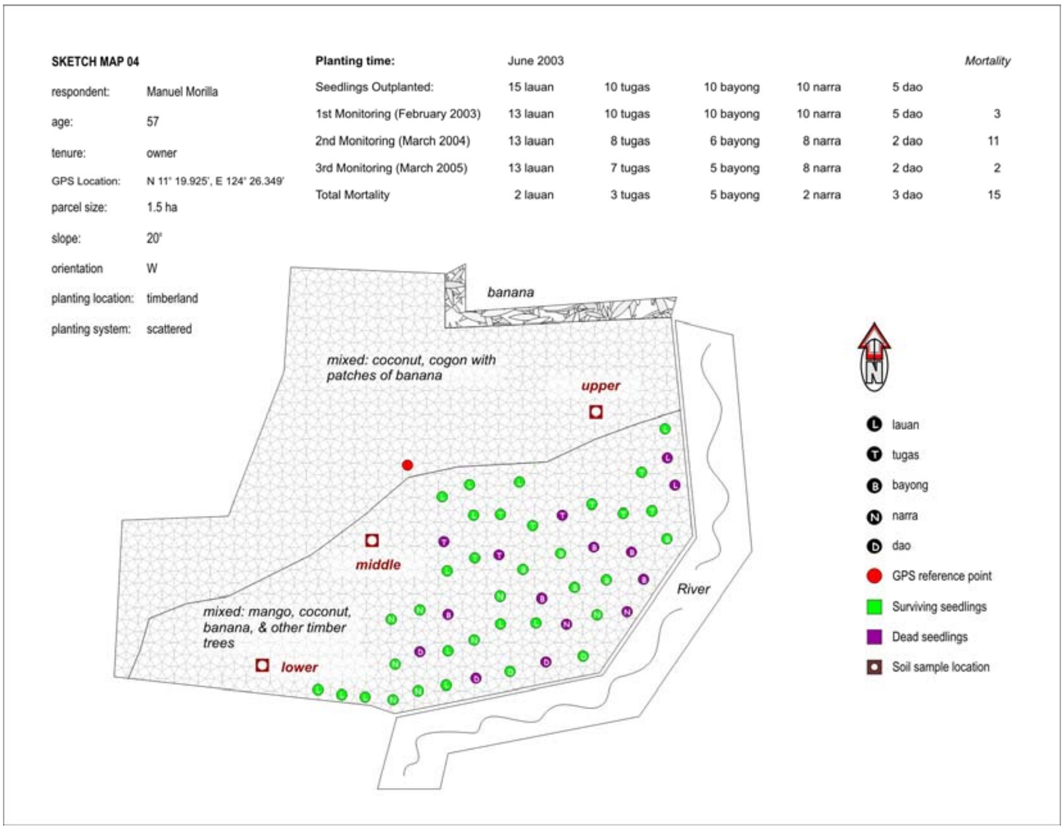


SKETCH MAP 03

respondent: Alfredo Troyo Sr.
age: 78
tenure: owner
GPS Location: N 11° 20.183', E 124° 26.136'
parcel size: 4 ha
slope: 30°
orientation S
planting location: coconut plantation
planting system: line

Planting time:	June 2003					*Mortality*
Seedlings Outplanted:	20 lauan	10 tugas	5 bayong	10 narra	5 dao	
1st Monitoring (February 2003)	20 lauan	10 tugas	5 bayong	10 narra	5 dao	0
2nd Monitoring (March 2004)	14 lauan	9 tugas	5 bayong	7 narra	5 dao	10
3rd Monitoring (March 2005)	13 lauan	7 tugas	4 bayong	6 narra	5 dao	5
Total Mortality	7 lauan	3 tugas	1 bayong	4 narra	0 dao	15

Figure 3. Alfredo Troyo´s farm

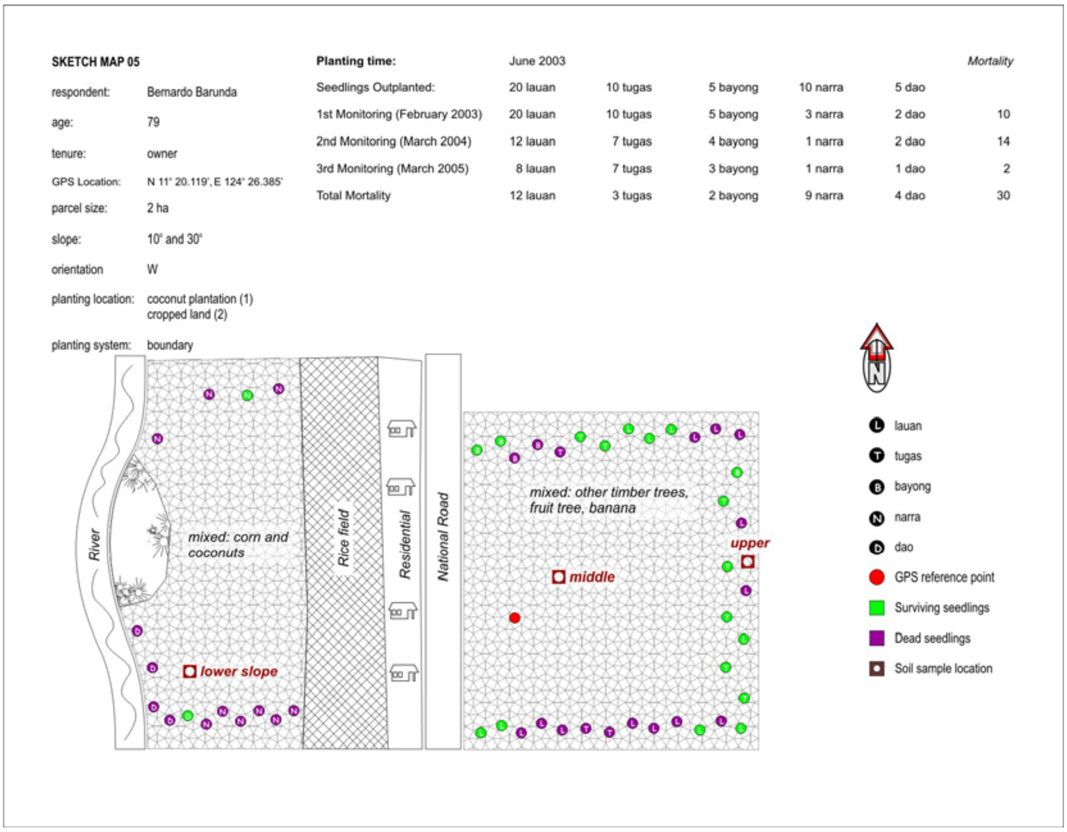


SKETCH MAP 04

respondent: Manuel Morilla
age: 57
tenure: owner
GPS Location: N 11° 19.925', E 124° 26.349'
parcel size: 1.5 ha
slope: 20°
orientation W
planting location: timberland
planting system: scattered

Planting time:	June 2003					*Mortality*
Seedlings Outplanted:	15 lauan	10 tugas	10 bayong	10 narra	5 dao	
1st Monitoring (February 2003)	13 lauan	10 tugas	10 bayong	10 narra	5 dao	3
2nd Monitoring (March 2004)	13 lauan	8 tugas	6 bayong	8 narra	2 dao	11
3rd Monitoring (March 2005)	13 lauan	7 tugas	5 bayong	8 narra	2 dao	2
Total Mortality	2 lauan	3 tugas	5 bayong	2 narra	3 dao	15

Figure 4. Manuel Morilla´s farm

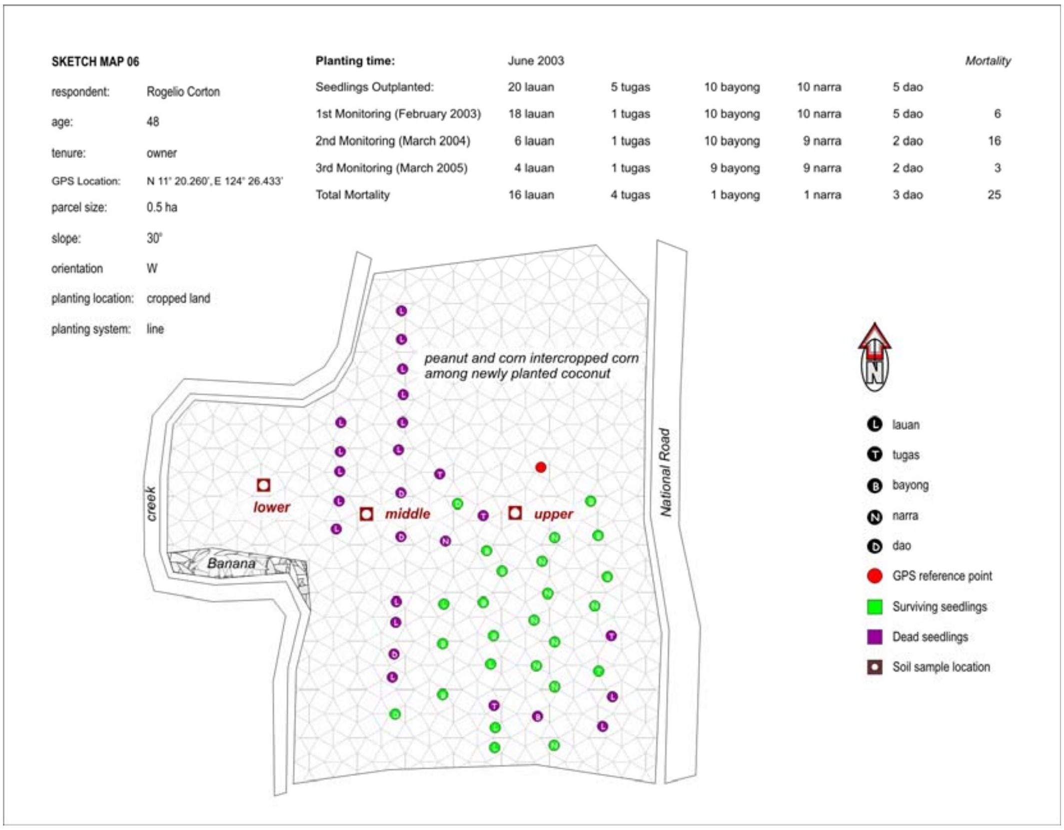


SKETCH MAP 05

respondent: Bernardo Barunda
age: 79
tenure: owner
GPS Location: N 11° 20.119', E 124° 26.385'
parcel size: 2 ha
slope: 10° and 30°
orientation W
planting location: coconut plantation (1)
cropped land (2)
planting system: boundary

Planting time:	June 2003					*Mortality*
Seedlings Outplanted:	20 lauan	10 tugas	5 bayong	10 narra	5 dao	
1st Monitoring (February 2003)	20 lauan	10 tugas	5 bayong	3 narra	2 dao	10
2nd Monitoring (March 2004)	12 lauan	7 tugas	4 bayong	1 narra	2 dao	14
3rd Monitoring (March 2005)	8 lauan	7 tugas	3 bayong	1 narra	1 dao	2
Total Mortality	12 lauan	3 tugas	2 bayong	9 narra	4 dao	30

Figure 5. Bernardo Barunda´s

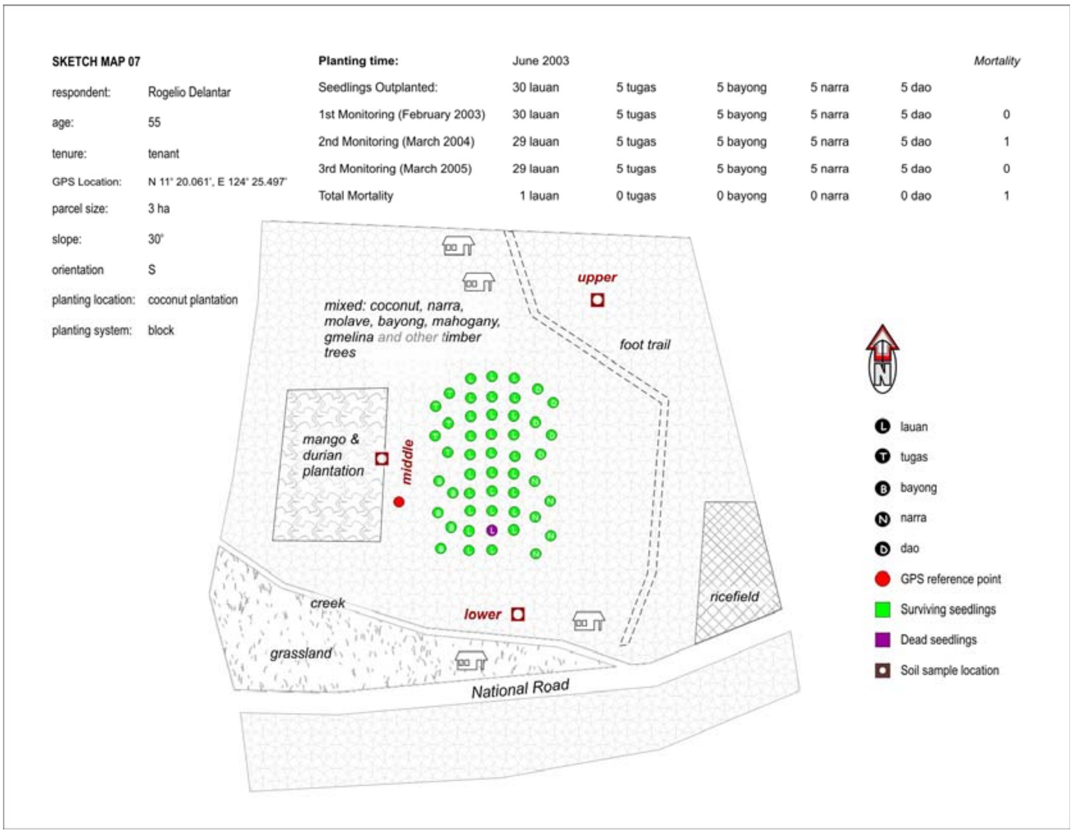


SKETCH MAP 06

respondent: Rogelio Corton
age: 48
tenure: owner
GPS Location: N 11° 20.260', E 124° 26.433'
parcel size: 0.5 ha
slope: 30°
orientation W
planting location: cropped land
planting system: line

Planting time:	June 2003					*Mortality*
Seedlings Outplanted:	20 lauan	5 tugas	10 bayong	10 narra	5 dao	
1st Monitoring (February 2003)	18 lauan	1 tugas	10 bayong	10 narra	5 dao	6
2nd Monitoring (March 2004)	6 lauan	1 tugas	10 bayong	9 narra	2 dao	16
3rd Monitoring (March 2005)	4 lauan	1 tugas	9 bayong	9 narra	2 dao	3
Total Mortality	16 lauan	4 tugas	1 bayong	1 narra	3 dao	25

Figure 5. Rogelio Corton´s

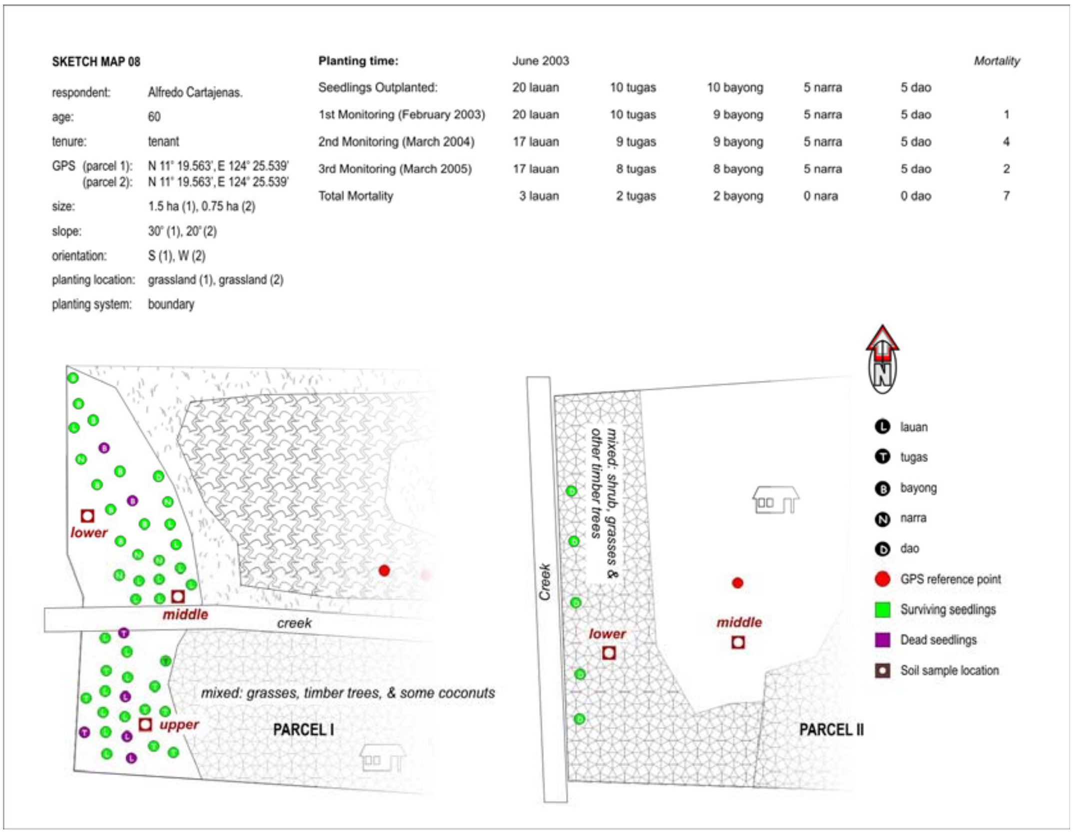


SKETCH MAP 07

respondent:	Rogelio Delantar
age:	55
tenure:	tenant
GPS Location:	N 11° 20.061', E 124° 25.497'
parcel size:	3 ha
slope:	30°
orientation	S
planting location:	coconut plantation
planting system:	block

Planting time:	June 2003					*Mortality*
Seedlings Outplanted:	30 lauan	5 tugas	5 bayong	5 narra	5 dao	
1st Monitoring (February 2003)	30 lauan	5 tugas	5 bayong	5 narra	5 dao	0
2nd Monitoring (March 2004)	29 lauan	5 tugas	5 bayong	5 narra	5 dao	1
3rd Monitoring (March 2005)	29 lauan	5 tugas	5 bayong	5 narra	5 dao	0
Total Mortality	1 lauan	0 tugas	0 bayong	0 narra	0 dao	1

Figure 7. Rogelio Delantar´s

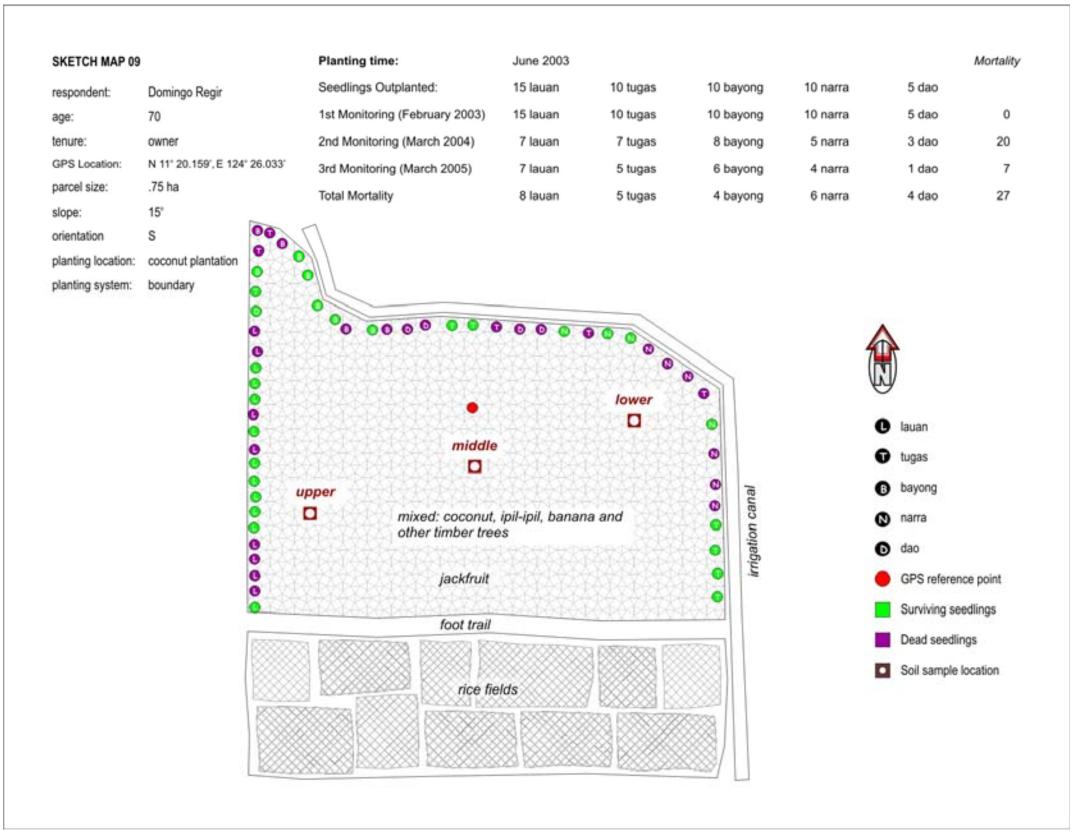


SKETCH MAP 08

respondent:	Alfredo Cartajenas.
age:	60
tenure:	tenant
GPS (parcel 1): (parcel 2):	N 11° 19.563', E 124° 25.539' N 11° 19.563', E 124° 25.539'
size:	1.5 ha (1), 0.75 ha (2)
slope:	30° (1), 20° (2)
orientation:	S (1), W (2)
planting location:	grassland (1), grassland (2)
planting system:	boundary

Planting time:	June 2003					*Mortality*
Seedlings Outplanted:	20 lauan	10 tugas	10 bayong	5 narra	5 dao	
1st Monitoring (February 2003)	20 lauan	10 tugas	9 bayong	5 narra	5 dao	1
2nd Monitoring (March 2004)	17 lauan	9 tugas	9 bayong	5 narra	5 dao	4
3rd Monitoring (March 2005)	17 lauan	8 tugas	8 bayong	5 narra	5 dao	2
Total Mortality	3 lauan	2 tugas	2 bayong	0 nara	0 dao	7

Figure 8. Alfredo Cartajenas´

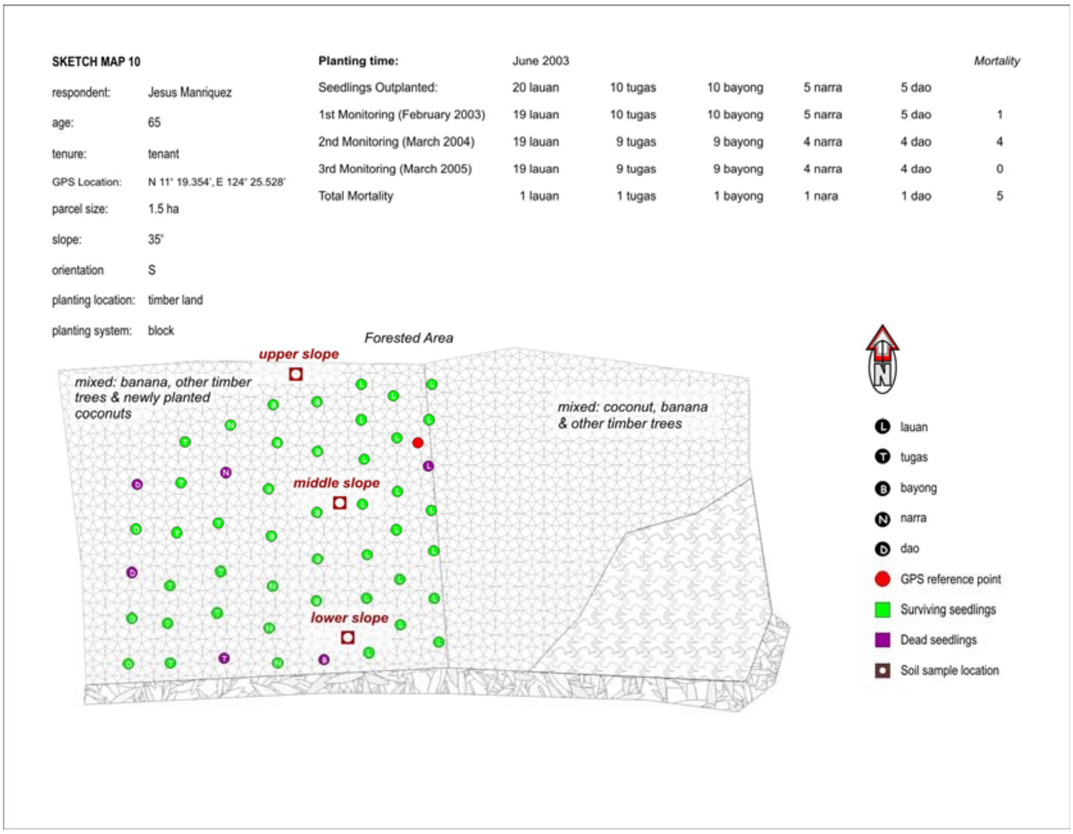


SKETCH MAP 09

respondent: Domingo Regir
age: 70
tenure: owner
GPS Location: N 11° 20.159', E 124° 26.033'
parcel size: .75 ha
slope: 15°
orientation S
planting location: coconut plantation
planting system: boundary

Planting time:	June 2003					*Mortality*
Seedlings Outplanted:	15 lauan	10 tugas	10 bayong	10 narra	5 dao	
1st Monitoring (February 2003)	15 lauan	10 tugas	10 bayong	10 narra	5 dao	0
2nd Monitoring (March 2004)	7 lauan	7 tugas	8 bayong	5 narra	3 dao	20
3rd Monitoring (March 2005)	7 lauan	5 tugas	6 bayong	4 narra	1 dao	7
Total Mortality	8 lauan	5 tugas	4 bayong	6 narra	4 dao	27

Figure 8. Domingo Regir´s farm

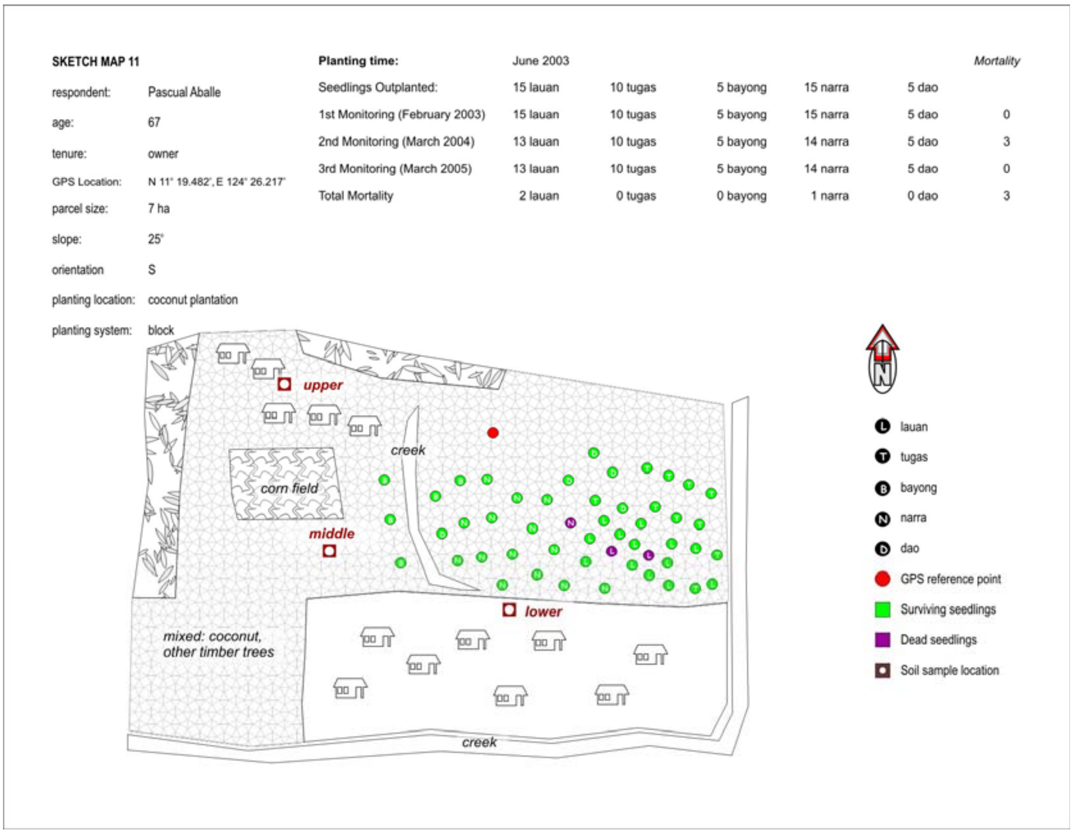


SKETCH MAP 10

respondent: Jesus Manriquez
age: 65
tenure: tenant
GPS Location: N 11° 19.354', E 124° 25.528'
parcel size: 1.5 ha
slope: 35°
orientation S
planting location: timber land
planting system: block

Planting time:	June 2003					*Mortality*
Seedlings Outplanted:	20 lauan	10 tugas	10 bayong	5 narra	5 dao	
1st Monitoring (February 2003)	19 lauan	10 tugas	10 bayong	5 narra	5 dao	1
2nd Monitoring (March 2004)	19 lauan	9 tugas	9 bayong	4 narra	4 dao	4
3rd Monitoring (March 2005)	19 lauan	9 tugas	9 bayong	4 narra	4 dao	0
Total Mortality	1 lauan	1 tugas	1 bayong	1 nara	1 dao	5

Figure 10. Jesus Manriquez´s farm

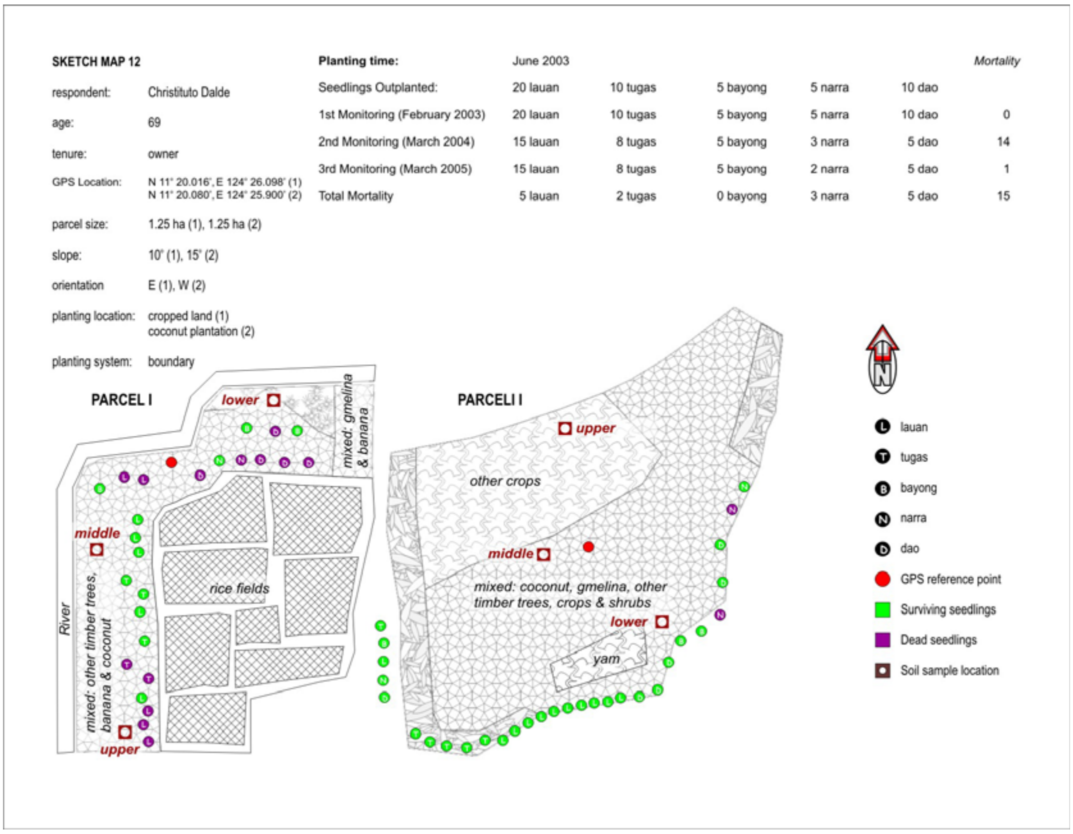


SKETCH MAP 11

respondent: Pascual Aballe
age: 67
tenure: owner
GPS Location: N 11° 19.482', E 124° 26.217'
parcel size: 7 ha
slope: 25°
orientation S
planting location: coconut plantation
planting system: block

Planting time:	June 2003					*Mortality*
Seedlings Outplanted:	15 lauan	10 tugas	5 bayong	15 narra	5 dao	
1st Monitoring (February 2003)	15 lauan	10 tugas	5 bayong	15 narra	5 dao	0
2nd Monitoring (March 2004)	13 lauan	10 tugas	5 bayong	14 narra	5 dao	3
3rd Monitoring (March 2005)	13 lauan	10 tugas	5 bayong	14 narra	5 dao	0
Total Mortality	2 lauan	0 tugas	0 bayong	1 narra	0 dao	3

Figure 11. Pascual Aballe´s farm

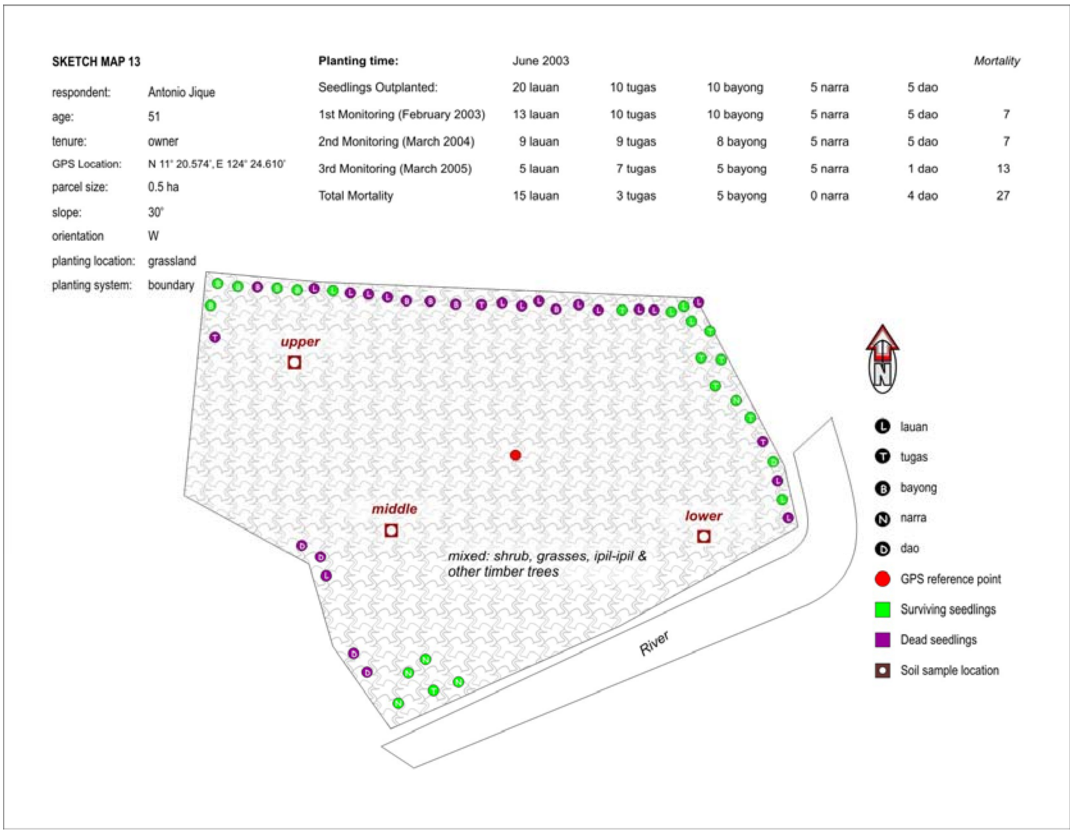


SKETCH MAP 12

respondent: Christituto Dalde
age: 69
tenure: owner
GPS Location: N 11° 20.016', E 124° 26.098' (1)
N 11° 20.080', E 124° 25.900' (2)
parcel size: 1.25 ha (1), 1.25 ha (2)
slope: 10° (1), 15° (2)
orientation E (1), W (2)
planting location: cropped land (1)
coconut plantation (2)
planting system: boundary

Planting time:	June 2003					*Mortality*
Seedlings Outplanted:	20 lauan	10 tugas	5 bayong	5 narra	10 dao	
1st Monitoring (February 2003)	20 lauan	10 tugas	5 bayong	5 narra	10 dao	0
2nd Monitoring (March 2004)	15 lauan	8 tugas	5 bayong	3 narra	5 dao	14
3rd Monitoring (March 2005)	15 lauan	8 tugas	5 bayong	2 narra	5 dao	1
Total Mortality	5 lauan	2 tugas	0 bayong	3 narra	5 dao	15

Figure 12. Christituto Dalde´s farm

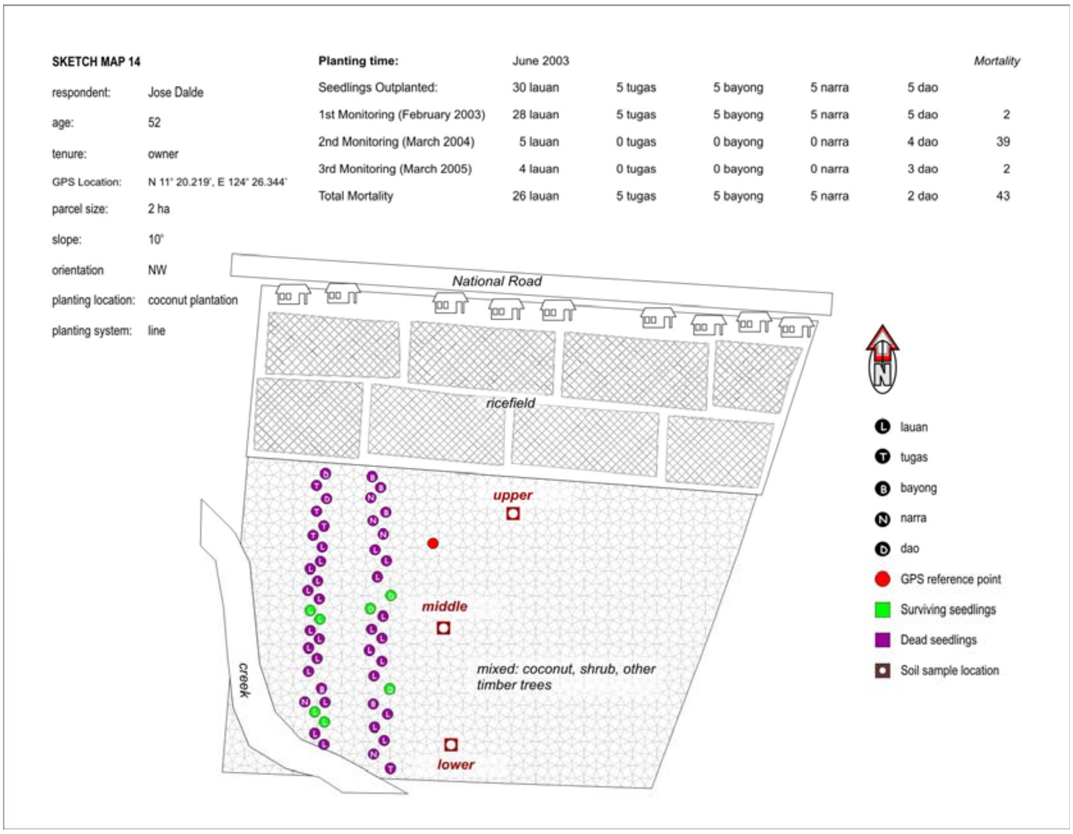


SKETCH MAP 13

respondent:	Antonio Jique
age:	51
tenure:	owner
GPS Location:	N 11° 20.574', E 124° 24.610'
parcel size:	0.5 ha
slope:	30°
orientation	W
planting location:	grassland
planting system:	boundary

Planting time:	June 2003					*Mortality*
Seedlings Outplanted:	20 lauan	10 tugas	10 bayong	5 narra	5 dao	
1st Monitoring (February 2003)	13 lauan	10 tugas	10 bayong	5 narra	5 dao	7
2nd Monitoring (March 2004)	9 lauan	9 tugas	8 bayong	5 narra	5 dao	7
3rd Monitoring (March 2005)	5 lauan	7 tugas	5 bayong	5 narra	1 dao	13
Total Mortality	15 lauan	3 tugas	5 bayong	0 narra	4 dao	27

Figure 13. Antonio Jique´s farm

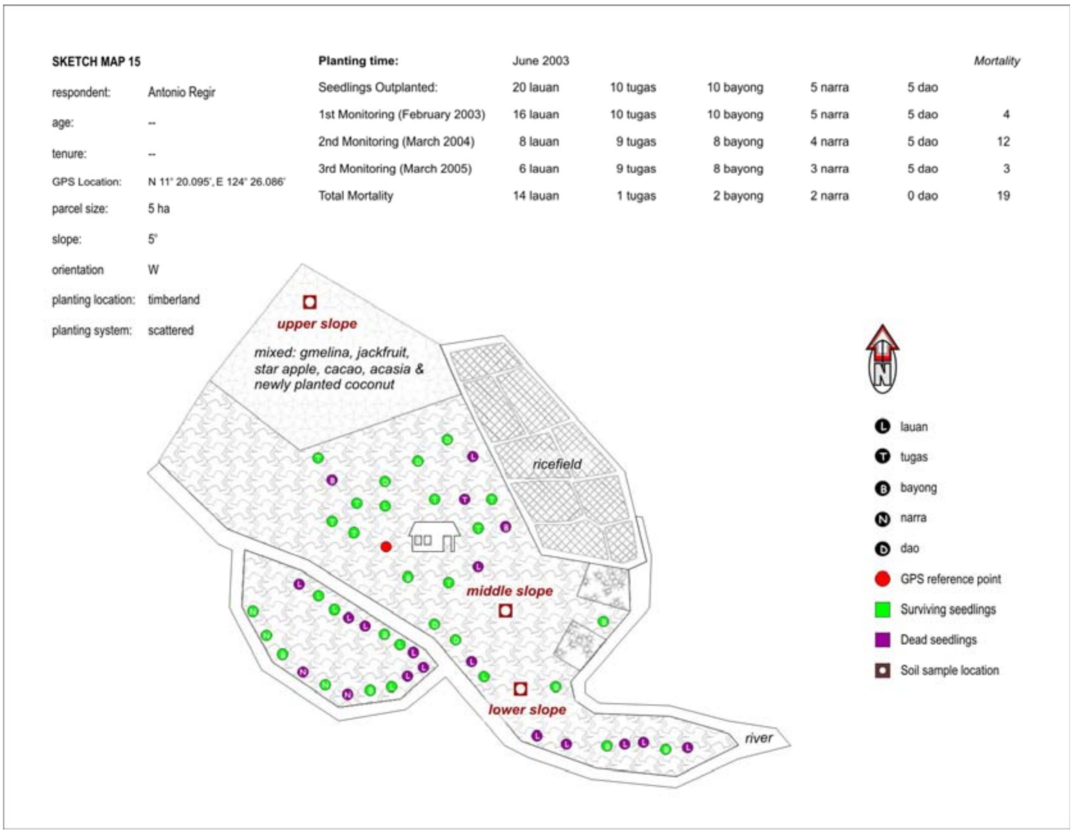


SKETCH MAP 14

respondent:	Jose Dalde
age:	52
tenure:	owner
GPS Location:	N 11° 20.219', E 124° 26.344'
parcel size:	2 ha
slope:	10°
orientation	NW
planting location:	coconut plantation
planting system:	line

Planting time:	June 2003					*Mortality*
Seedlings Outplanted:	30 lauan	5 tugas	5 bayong	5 narra	5 dao	
1st Monitoring (February 2003)	28 lauan	5 tugas	5 bayong	5 narra	5 dao	2
2nd Monitoring (March 2004)	5 lauan	0 tugas	0 bayong	0 narra	4 dao	39
3rd Monitoring (March 2005)	4 lauan	0 tugas	0 bayong	0 narra	3 dao	2
Total Mortality	26 lauan	5 tugas	5 bayong	5 narra	2 dao	43

Figure 14. Jose Dalde´s



SKETCH MAP 15

respondent: Antonio Regir

age: --

tenure: --

GPS Location: N 11° 20.095', E 124° 26.086'

parcel size: 5 ha

slope: 5°

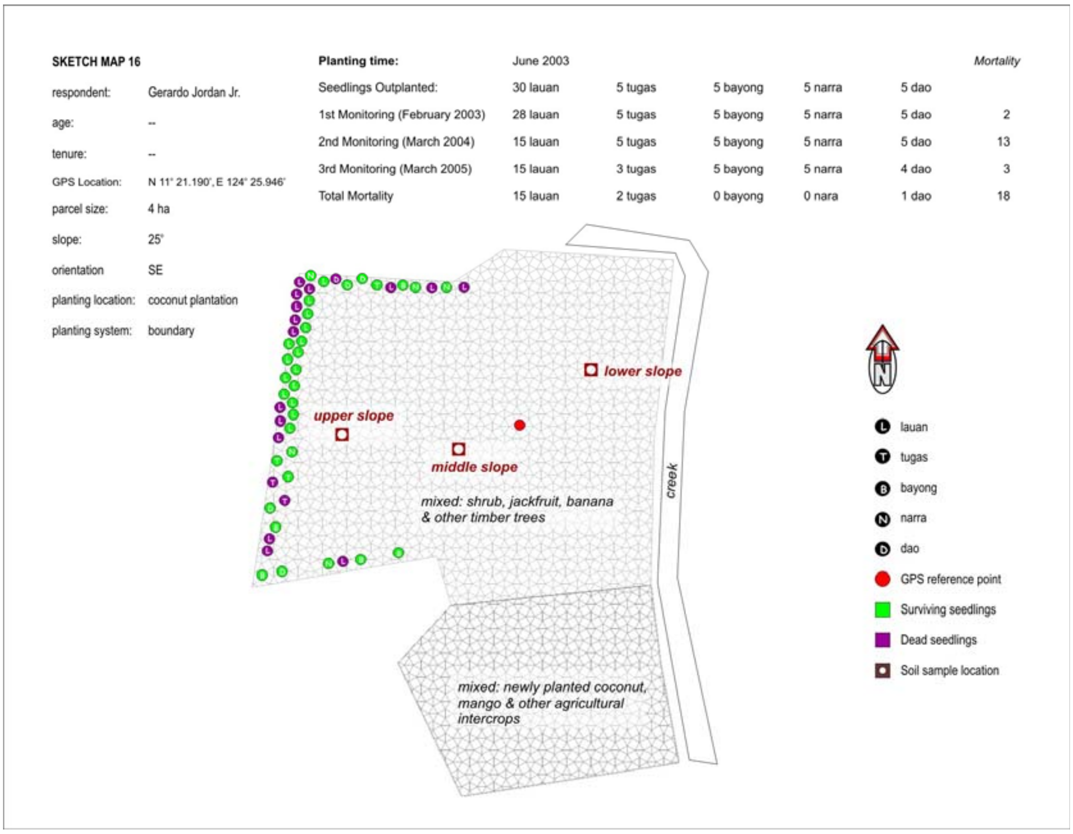
orientation W

planting location: timberland

planting system: scattered

Planting time:	June 2003					Mortality
Seedlings Outplanted:	20 lauan	10 tugas	10 bayong	5 narra	5 dao	
1st Monitoring (February 2003)	16 lauan	10 tugas	10 bayong	5 narra	5 dao	4
2nd Monitoring (March 2004)	8 lauan	9 tugas	8 bayong	4 narra	5 dao	12
3rd Monitoring (March 2005)	6 lauan	9 tugas	8 bayong	3 narra	5 dao	3
Total Mortality	14 lauan	1 tugas	2 bayong	2 narra	0 dao	19

Figure 15. Antonio Regir´s



SKETCH MAP 16

respondent: Gerardo Jordan Jr.

age: --

tenure: --

GPS Location: N 11° 21.190', E 124° 25.946'

parcel size: 4 ha

slope: 25°

orientation SE

planting location: coconut plantation

planting system: boundary

Planting time:	June 2003					Mortality
Seedlings Outplanted:	30 lauan	5 tugas	5 bayong	5 narra	5 dao	
1st Monitoring (February 2003)	28 lauan	5 tugas	5 bayong	5 narra	5 dao	2
2nd Monitoring (March 2004)	15 lauan	5 tugas	5 bayong	5 narra	5 dao	13
3rd Monitoring (March 2005)	15 lauan	3 tugas	5 bayong	5 narra	4 dao	3
Total Mortality	15 lauan	2 tugas	0 bayong	0 nara	1 dao	18

Figure 16. Gerardo Jordan´s farm

ANNEX 3: NATIVE TREE SPECIES DESCRIPTION

1. *Shorea contorta* Vidal (Dipterocarpaceae) / Common name: White Lauan

Distribution: Endemic to the Philippines, from Luzon to northern Mindanao.

Ecology: Was common and occurred often semi-gregarious in seasonal semi-evergreen forest of up to 700 m altitude.

Description: A large tree reaching 50 m tall and 180 cm dbh, but often only medium sized. Crown green. Buttresses present. Bark brown to nearly black or grey when exposed to sunlight, V-fissured with vertical white strips of lenticels in the fissures. Slash inner bark brown to slightly pinkish stringy. Twigs not drooping; twigs round. Stipules falling early. Petiole not kneed; 1.7-3.5 cm; glabrous. Leaves elliptical or ovate, 9-29 x 5.5 – 11 cm; leathery; apex long-acuminate; base rounded, truncate, or subcordate, symmetrical or asymmetrical; Upper surface drying yellowish brown or brown, smooth to the touch; lower surface drying brown, smooth to the touch; glabrous; secondary nerves 5-9, arching along their length, stoutly prominent, remaining separate, same colour as lamina; tertiary nerves clearly visible, scalariform or subscalariform; domatia absent. Flowers: petals white; stamens 15. Mature fruits: long wings 8 – 12 x 1.2 – 3 cm; short wings 3 – 9 x 0.7 – 15 cm; nut 15 – 35 x 11 – 15 mm. Wood density is 420 – 560 kg / m3 at 15% moisture content.

Phenology: Flowering from March to May, fruiting from April to July.

Uses: In the Philippines is traded as one of the most important timber of the country.

2. *Vitex parviflora* Juss., (Verbenaceae) / Common name: Molave (Phi.)

Distribution: Native to the Philippines easily found in East Indonesia.

Ecology: Grows naturally in open primary and secondary lowland tropical forests up to 700 m altitude, preferably on limestone or volcanic soils, in areas with a distinct dry season. In natural conditions is often an element of the upper storey of the forest canopy and is sometime found as a dominant tree together with Narra (Pterocarpus indicus).

Description: A medium sized deciduous tree up to 30 m tall and 1.5 m in diameter with an open wide-spreading crown and sometimes buttresses. The greyish ochre fibrous bark is smooth or thinly flaked. Leaves opposite, palmately compound on 9–11 cm long leaf stalk, with 3–5 shiny and glabrous, lance-shaped, pointed leaflets, 4–15 cm long and 2.5–7 cm wide on 3–10 mm long stalks. Inflorescence is about 20 cm long pyramid-shaped panicle with many bluish flowers, 6–8 mm long. The fruits are small, round drupes, 5–10 mm in diameter, purple to black when ripe.

Uses: The wood is used for furniture making, cabinets, decorative veneers and other specialty items and can also produce a red dye. The tree is also used as a shade tree for other crops and as an ornamental.

3. *Pterocarpus indicus* Willd. (Leguminosae) / Common name: Narra (Phil.)

Distribution: Native in Southeast Asia. Widely distributed in the Philippines. Cultivated now also in Africa and Central America.

Ecology: Occurs mainly in along tidal creeds and rocky shore, mostly in evergreen forest, but also in seasonal forest up to 600 m altitude, but may grow in higher altitudes as well when planted. Is a nitrogen fixing tree and demands lights.

Description: A medium sized deciduous tree up to 45 m tall and 2 m in diameter with fluted trunk and more or less pronounced buttresses, wide spreading crown with lower branches drooping and touching the ground. Bark smooth, light yellow-brown, 0.5 cm thick, exuding red sap when cut. The wood smell like camphor or cedar. Leaves oddly pinnate, 15–30 cm long with 7–11 alternate leaflets, each 5–10 cm, ovate to oblong ovate, blunt pointed and shiny, largest leaflets towards tip of leaf. The numerous yellow showy and fragrant flowers are 1.5 cm long, arranged in branched panicles. Seed pods are soft haired when young, becoming (almost) smooth when mature. Pods, including the 1–1.5 cm wide surrounding wing, are circular, flat, 4–5.5 cm in diameter and about 0.5 cm thick.

Phenology: In general, new leaves develop simultaneously with the flowers at the beginning of the rain season. In areas with no distinct wet and dry seasons, gregarious flowering does not occur frequently, and instead flowering is asynchronous.

Use: Is a well known hard wood very appreciate for the timber industry. It is used mainly as a structural timber for construction, furniture, veneer, plywood and cabinet work. Due to its reddish colour, is ranked among the finest for furniture, planeling and musical instrument.

4. *Artocarpus heterophyllus* Lamk (Moraceae) / Common name: Nangka

Distribution: Is most probably indigenous to India, but since time immemorial it has been cultivated and became naturalized in many parts of Southeast Asia, i.e. the Philippines.

Ecology: From sea level up to more than 500 m altitudes. Is planted mainly in home gardens and mixed orchard and proofed, therefore, very good prospects for the incorporation into multispecies farming systems.

Description: Trees to 18 m, 50 cm dbh; not or scarcely buttressed. Bark grey-brown, smooth to somewhat scaly. Sapwood white. Twigs 2 – 6 mm, with scattered yellow hair or glabrous and with ring-like scars present. Simple leaves, thin leathery, elliptic, abovate to subrotund, 5 – 25 x 2 – 15 cm, glabrous above. Inflorescences solitary in the leaf axils, from the trunk and secondary brances on short leafy shoots. Seeds oblong-elipsoid 15 – 20 mm. covered in a thin, yellow gelatinous coat.

Phenology: Seeds are usually rated as recalcitrant and loose their viability very rapidly. Nevertheless, seeds may remain viable when dept inside the fruit. Germination usually starts 10 – 40 days after sowing. Seedlings should be raised under shade (50 – 70 % of full light intensity).

Uses: The timber is classified as medium hardwood; it is resistant to termite attack, fungal and bacterial decay, easy to season and takes polish beautifully. The pulp of fruit is cooked as vegetable or eaten fresh. Young leaves are readily eaten by cattle and other livestock.

6. References

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ANNEX 4: WANULCAS 3.1 CORE MODULE INPUT PARAMETERS AND THEIR DEFINITION

⬛ Direct input for WaNuLCAS
🟦 Indirect input : fine tuning using submodel
🟥 Indirect input : Pedotransfer, FBA, WOFOST
🟩 Indirect input : Semiquantitative observation, reference, 'arbo'transfer
🟪 Controls of option

Abbreviations used in parameter names

No	Acronym	Definition	No	Acronym	Definition
1.	AF	"Agroforestry Zone" – overall design on the system	14.	Mn	Nutrients in Litter Layer
2.	C	Crop (T=Crop, C_N=Crop Nutrient or CW=Crop Water)	15.	Mn2	Nutrients in Soil Organic Matter (SOM)
3.	Ca	Crop Calendar (schedule)	16.	N	Nutrient (currently including N and P)
4.	Cent	Input Output Summary for Litter (based on Century Model)*	17.	P	Profitability (economic sector of the model)
5.	Cent2	Input Output Summary for SOM (based on Century Model)*	18.	PD	Pest and Disease
6.	Cq	Crop Sequence (crop parameters)	19.	Rain	Rain
7.	E	Erosion	20.	Rt	Root
8.	Evap	Evaporation	21.	S&B	Slash and Burn
9.	G	Grazing	22.	S	Soil Structure
10.	LF	Lateral Flow	23.	T	Tree (T=Tree, T_N=Tree Nutrient or TW=Tree Water)
11.	Light	Light	24.	TF	Tree Fruit (oil Palm Module)
12.	Mc	Carbon in Litter Layer	25.	Temp	Temperature
13.	Mc2	Carbon in Soil Organic Matter	26.	W	Water

* : parameter in stella (second layer)

No	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link in Excel)
1.	AF_DepthDynamic?	Parameter determining the dynamic of soil layer 1 on sloping land	dimensionless	0 or 1 (0)	Agroforestry Zone/System
2.	AF_DynPestImpacts?	Parameter governing an option to simulate system with pest impact dynamically	dimensionless	0 – 1 (0)	RUN & OUTPUT SECTION
3.	AF_PlotNumberUphil	Number of similar uphill plot neighbours as source of Lateral Inflow & Run-on	dimensionless	(0)	Agroforestry zone
4.	AF_RunOnFrac	Fraction of surface runoff from the area uphill that enters the simulation area as run-on.	dimensionless	0 – 1 (0)	Agroforestry Zone
5.	AF_SimulateWeeds?	Parameter governing an option to simulate weed growth.	%	0 or 1 (0)	RUN & OUTPUT SECTION
6.	AF_SlopeInit	Slope (expressed as percent elevation increment per horizontal distance) of the soil surface at the start of the simulation.	%	0 – 100 (0)	Agroforestry Zone/System
7.	AF_SlopeSoilHoriz	Slope of the soil horizons below the surface	%	0 – 100 (0)	Agroforestry Zone/System
8.	AF_StoneFrac[Zone,SoilLayer]	Fraction of stone in each soil year and zone	dimensionless	0 – 1 (0)	Agroforestry Zone
9.	C_ApplyMaintResp?	On/Off switch for applying the maintenance respiration,;	dimensionless	0 or 1 (0)	Maintenance Respiration
10.	C_DailyWeedSeedDecayFrac	Fraction of the weed seed bank that looses viability and is transferred to the litter pool for decomposition	fraction day^{-1}	0 – 1 (.02)	Management/Weed Growth
11.	C_HostEffForT1[Cr]	An option for simulation root parasitism crop 1 on others crop root	dimensionless	(0)	Root Parasitism
12.	C_RelRespGroRes	Relative weighting factor for growth reserves as part of total biomass as used for maintenance respiration	dimensionless	(.5)	Maintenance Respiration
13.	C_RelRespRt	Relative weighting factor for roots as part of total biomass as used for maintenance respiration	dimensionless	(.3)	Maintenance Respiration
14.	C_RelRespStLv	Relative weighting factor for stem & leaves as part of total biomass as used for maintenance respiration	dimensionless	(.5)	Maintenance Respiration
15.	C_RelRespYieldCurr	Relative weighting factor for developing fruit	dimensionless	(1)	Maintenance Respiration
16.	C_ResidRemovalFrac	Fraction of crop residue removed from field (not returned as mulch).	fraction	0 – 1 (0)	Management/ Mulching
17.	C_RespperBiom	Use of resources for maintenance respiration per unit biomass	dimensionless	0 – 0.2 (.05)	Maintenance Respiration
18.	C_RespTemp	A graphical relation between temperature and respiration	dimensionless	(see C_RespTemp graph)	Maintenance Respiration
19.	C_WeedGermFrac	Fraction of weed seeds in the seed bank that germinates when a new opportunity arises	fraction	0 –1 (.1)	Management/Weed Growth
20.	C_WeedSeedBankInit	Initial dry weight of weed seeds in seed bank	kg m^{-2}	0 –1 (.01)	Management/Weed Growth
21.	C_WeedSeedExtInflux	Daily influx of weed seeds from outside of the plot	kg m^{-2} day^{-1}	0 – 0.1 (.00001)	Management/Weed Growth
22.	Ca_ImmAmount[P,Zone]	Amount of immobile P fertilizer applied.	g m^{-2}	(ImmAmount graph)	Management/P Immobile Input

No	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link in Excel)
23.	Ca_ImmDOY[P]	Time of immobile P fertilizer application.	Julian days	(see Ca_ImmDOY graph)	Management/P Immobile Input
24.	Ca_ImmY[P]	Year of immobile P fertilizer application.	dimensionless	(see Ca_ImmY graph)	Management/P Immobile Input
25.	Cq_CovEff[Cr]	Crop Cover Efficiency factor, used in calculating erosion	dimensionless	0 – 1 (1)	(Crop Library /Soil Erosion)
26.	Cq_MycMaxInf[Cr]	Fraction of crop roots infected by mychorrhiza for a soil layer where the Rt_MTInfFrac parameter is 1	dimensionless	0 – 1 (.25)	(Crop Library/ Mycorrhiza Fraction)
27.	Cq_NutMobC [Cr,SiNut]	Relative rate of transfer, per unit root length density (cm cm-3)	m^2 day^{-1}	0 – 0.02 (0)	Crop Library
28.	Cq_WeedType	Weed type. This is user defined.	dimensionless	(5)	Management/ Weed Growth
29.	E_CovEffT[Tree]	Tree cover efficiency factor (per unit tree LAI)	dimensionless	0 – 1 (.5)	(Tree library)
30.	E_Entrailment CoeffBarePlot	Entrailment coefficient for sediment movement (Rose equation) in the absence of vegetative soil cover	kg^{-1} (soil) mm^{-1} m^2	0 – 1 (.002)	Soil Erosion and Sedimentation
31.	E_ErosiType	Parameter to decide on model of erosion used.	dimensionless	0 or 1 (0)	Soil Erosion and Sedimentation
32.	E_IntvPloughPlant	Length of ploughing time	Julian days	1 – 365 (10)	Management
33.	E_PloughBefPlant?	Parameter governing option to plough before planting	dimensionless	0 or 1 (0)	Management
34.	E_PloughDoY	Date of ploughing	Julian days	1 – 365 (364)	Management
35.	E_PloughY	Year of ploughing	dimensionless	0 – 100 (100)	Management
36.	E_RainFac	A multiplier determining impact of rainfall on soil erosion, USLE	dimensionless	0 – 10 (1)	Soil Erosion and Sedimentation
37.	E_SoilMoveper Plough	Amount of soil moved per ploughing event, USLE	kg m^{-2}	0 – 500 (399)	Soil Erosion and Sedimentation
38.	E_SoilType	Type of soil. 1 = medium, 2 = sandy, 3 = clay	dimensionless	1, 2, 3 (1)	Soil Erosion and Sedimentation
39.	E_TillZone?[Zone]	On/pff switch for tilling in each zone	dimensionless	0 or 1	Management/ Tillage
40.	LF_SubSurfInflow4	Amount of sub surface water inflow in layer 4	mm day^{-1}	0 – 5 (0)	Agroforestry zone
41.	N_BypassMacro*i* [Zone]	Prefential flows of nutrients in the leachate relative to average concentration * water flow	dimensionless	0 – 2 (1)	Soil Water and Nutrient
42.	N_DiffCoef[SiNut]	Nitrogen diffusion coefficient	cm^2 day^{-1}	0 - 1	Soil Water and Nutrient
43.	N_ImInit [Zone,SiNut]	Initial amount of nutrient in immobile pool of each zone	mg cm^{-3}	0 – 0.1 (N = .05, P = .01)	Soil Water and Nutrient
44.	N_Lat4InflowRelCon c	Nutrient concentrations in the incoming sub-surface flows into zone 4.	dimensionless	0 – 10 (1)	Agroforestry Zone
45.	N_NutMob*i*[SiNut]	Relative rate of transfer from the 'immobile' pool of nutrients to the 'mobile' or sorbed pool.	day^{-1}	0 – 0.02 (0)	Soil Nutrient /Mobilization

No	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link in Excel)
46.	N_RtSynloc*i*	Root synlocation, degree to which roots of crop and tree are occurring within the various soil layers	dimensionless	0 – 1 (.5)	Roots and Mycorrhiza
47.	P_BurnLab	Amount of labour involved in burning the field per unit simulated filed	person days ha^{-1}	(see excel sheet Profitability)	(Profitability)
48.	P_CfertPrice [SiNut,Price]	Cost of fertilizer at social and private prices, respectively.	currency unit kg^{-1}	(see excel sheet Profitability)	(Profitability)
49.	P_CHarvLab[Cr]	Amount of labour involved in harvesting crop per unit dry weight	person days Mg^{-1}	(see excel sheet Crop Library)	(Profitability)
50.	P_CPestContLab[Cr]	Amount of labour involved in pest control per cropping season	person days ha^{-1}	(see excel sheet Crop Library)	(Profitability)
51.	P_CpestContPrice [Price]	Amount of direct costs (outside labour) involved in pest control per cropping season	currency unit per ha^{-1}	(see excel sheet Profitability)	(Profitability)
52.	P_CPlantLab[Cr]	Amount of labour involved in planting per cropping season	person days ha^{-1}	(see excel sheet Crop Library)	(Profitability)
53.	P_CSeedPrice [Cr,Price]	Cost of crop seed per kg at social and private prices, respectively.	currency unit kg^{-1}	(see excel sheet Crop Library)	(Profitability)
54.	P_CWeedLab[Cr]	Amount of labour involved in weeding per cropping season	person days ha^{-1}	(see excel sheet Crop Library)	(Profitability)
55.	P_CyieldPrice[Cr, Price]	Price of crop yield per unit dry weight at social and private prices.	currency unit kg^{-1}	(see excel sheet Crop Library)	(Profitability)
56.	P_DiscountRate	Discount rate (%) that applies to both social and private prices	% year^{-1}	(see excel sheet Profitability)	(Profitability)
57.	P_ExtOrgPrice [Type,Price]	Price of external organic input	currency unit kg-1	(see excel sheet Profitability)	(Profitability)
58.	P_FenceMatCost [Price]	Price of off-farm material used for building or maintaining a fence around the field	currency unit ha^{-1}	(see excel sheet Profitability)	(Profitability)
59.	P_TFruitHarvLab	Amount of labour involved in harvesting fruits per unit dry weight	person days kg^{-1}	(see excel sheet Tree Library)	(Profitability)
60.	P_TFruitPrice[Price]	Price of tree fruit yield per unit dry weight at social and private prices, respectively.	currency unit kg^{-1}	(see excel sheet Tree Library)	(Profitability)
61.	P_TLatexHarvLab	Amount of labour involved in harvesting latex per unit dry weight	person days kg^{-1}	(see excel sheet Tree Library)	(Profitability)
62.	P_TLatexPrice[Price]	Price of tree latex yield per unit dry weight at social and private prices.	currency unit kg^{-1}	(see excel sheet Tree Library)	(Profitability)
63.	P_TPlantLab	Amount of labour involved in planting trees per unit dry weight	person days kg^{-1}	(see excel sheet Tree Library)	(Profitability)
64.	P_TPrunLab[Tree]	Amount of labour involved in pruning trees per unit dry weight	person days kg^{-1}	(see excel sheet Tree Library)	(Profitability)
65.	P_TPrunPrice[Price]	Price of tree prunings harvested from the field per unit dry weight at social and private prices.	currency unit kg^{-1}	(see excel sheet Tree Library)	(/Profitability)
66.	P_TSeedPrice[Price]	Costs of tree planting material per unit initial tree biomass at social and private prices, respectively.	currency unit tree^{-1}	(see excel sheet Tree Library)	(/Profitability)
67.	P_TWoodHarvLab	Amount of labour involved in harvesting wood products per unit dry weight	person days kg$^{=1}$	(see excel sheet Tree Library)	(Profitability)
68.	P_TWoodPrice[Price]	Price of tree wood product yield per unit dry weight at social and private prices.	currency unit kg^{-1}	(see excel sheet Tree Library)	Profitability)

No	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link in Excel)
69.	P_UnitLabCost[Price]	Cost per unit labour at social and private prices, respectively	currency unit person $days^{-1}$	(see excel sheet Profitability)	(Profitability)
70.	PD_CeatenBy [Cr,Animals]	Fraction of crop component lost if eaten by animals.	dimensionless	0 – 1 (0)	(Crop Library)
71.	PD_CFrugivore? [Animals]	A switch determining the presence of attack by each default animal.	dimensionless	0 or 1 (0)	Pest and Disease
72.	PD_CFrugivory[Cr]	Constant daily fraction of crop fruit biomass removed due to frugivores	dimensionless	0 – 1 (0)	Pest and Diseases
73.	PD_CHerbivore? [Animals]	A switch determining the presence of attack by each default animal.	dimensionless	0 or 1 (0)	Pest and Disease
74.	PD_CHerbivory[Cr]	Constant daily fraction of crop leaf biomass removed due herbivores	dimensionless	0 – 1 (0)	Pest and Diseases
75.	PD_CRhizovore? [Animals]	A switch determining the presence of attack by each default animal.	dimensionless	0 or 1 (0)	Pest and Disease
76.	PD_CRhizovory[Cr]	Constant daily fraction of crop root biomass removed due rhizovores	dimensionless	0 – 1 (0)	Pest and Diseases
77.	PD_FenceBuildDOY	Schedule for day of fencing for each fencing event. A graphical input.	Julian days	(PD_FenceBuildDOY graph)	Pest and Disease
78.	PD_FenceBuildLab	Amount of labour needed to build fence for each fencing event.	person days	(PD_FenceBuild Lab graph)	Pest and Disease
79.	PD_FenceBuildY	Schedule for year of fencing for each fencing event	dimensionless	(PD_FenceBuildY graph)	Pest and Disease
80.	PD_FenceDecK	Daily fractional decay of fence quality	day^{-1}	0 – 1 (.02)	Pest and Diseases
81.	PD_FenceFullQua	Maximum quality of fence	dimensionless	1 – 4 (2)	Pest and Diseases
82.	PD_FenceMaint?	Switch determining fence maintenance.	dimensionless	0 or 1 (0)	Pest and Disease
83.	PD_FenceMUnit	Unit improvement of fence quality once it falls below the threshold set in PD_FenceQThresh	dimensionless	0 – 2 (.25)	Pest and Disease
84.	PD_FenceQThresh	Threshold of (relative) fence quality below which labour will be used to repair the fence	dimensionless	0 – 2 (1.1)	Pests and Disease
85.	PD_HalfFenceTime	Time constant of decay of fence quality.	days	0 – 365 (50)	Pest and Disease
86.	PD_JumptheFence? [animals]	The degree to which animals are deterred by a fence	-	0 – 1 (0)	Pest and Diseases
87.	PD_PopDensOutside [animals]	Population density outside the plot, influencing the presence	-	0 or 1	Pest and Diseases
88.	PD_TEatenBy?[Animals]	A switch determining tree attacks by specific animals.	0 or 1 (0)	0 – 1 (0)	(Tree parameters)
89.	PD_TFrugivore? [Animals]	A switch determining the presence of attack by each default animal.	dimensionless	0 or 1 (0)	Pest and Disease
90.	PD_Tfrugivory& Abort[Tree]	Constant daily fraction of tree fruit biomass removed due frugivores	-	0 – 1 (0)	Pest and Diseases
91.	PD_THerbivore? [Animals]	A switch determining the presence of attack by each default animal.	dimensionless	0 or 1 (0)	Pest and Disease
92.	PD_THerbivory [Tree]	Constant daily fraction of tree leaf biomass removed due to herbivores	-	0 – 1 (0)	Pest and Diseases

No	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link in Excel)
93.	PD_TLignivory [Tree]	Constant daily fraction of tree woody stem biomass removed due to the action of lignivores	-	0 – 1 (0)	Pest and Diseases
94.	PD_TLignovore? [Animals]	A switch determining the presence of attack by each default animal.	dimensionless	0 or 1 (0)	Pest and Disease
95.	PD_TRhizovore? [Animals]	A switch determining the presence of attack by each default animal.	dimensionless	0 or 1 (0)	Pest and Disease
96.	PD_TRhizovory [Tree]	Constant daily fraction of tree root biomass removed due to rhizovores	-	0 – 1 (0)	Pest and Diseases
97.	Rt_MCHypDiam	Diameter of crop mycorrhizal hyphae	cm	0.001 – 0.05 (.01)	Roots & Mycorrhiza
98.	Rt_MCHypL	Length of crop mycorrhizal hyphae per unit infected root length	dimensionless	10 – 100 (100)	Roots & Mycorrhiza
99.	Rt_MCInfFrac*i*	Fraction of crop roots that is mycorrhizal (infected)	dimensionless	0 – 1	Roots & Mycorrhiza
100.	Rt_MTHypDiam	Diameter of tree mycorrhizal hyphae	cm	0.001 – 0.05 (.01)	Roots & Mycorrhiza
101.	Rt_MTHypL	Length of tree mycorrhizal hyphae per unit infected root length	dimensionless	10 – 100 (100)	Roots & Mycorrhiza
102.	Rt_MTInfFrac*i*[Zone]	Fraction of tree roots that is mycorrhizaal (infected)	dimensionless	0 – 1 (0)	Roots & Mycorrhiza
103.	Rt_THostEffForT1 [Tree]	An option for simulation root parasitism tree 1 on others tree root	dimensionless	(0)	Root Parasitism
104.	S&B_2ndFireafter Pileup	Number of days between puile up and secondary burn event	days	1 – 100 (5)	Management/Slash and Burn
105.	S&B_CritMoist	Moisture content of slashed necromass;	l kg^{-1}	0 – 1(.05)	Management/ Slash and Burn
106.	S&B_DeadWoodFuelFact	Temperature of the fire per unit dry weight of fuel in dead wood	$^{o}C\ kg^{-1}$	0 – 100 (.1)	Management/ Slash and Burn
107.	S&B_FirImpPSorption	Fire impacts on P sorption,	dimensionless	(see table Slash&Burn)	Management/ Slash and Burn
108.	S&B_FirIndPMobiliz	Fire impact on mobilization fraction of P	dimensionless	(see table Slash&Burn)	Management/ Slash and Burn
109.	S&B_FirMortSeedBank	Fractional mortality in the weed seed bank as a function of soil surface temperature increment	dimensionless	(see table Slash&Burn)	Management/ Slash and Burn
110.	S&B_FuelLoadFactor	Temperature of the fire per unit dry weight of fuel in slashed necromass and structural surface litter	$^{o}C\ kg^{-1}$	0 – 100 (10)	Management/ Slash and Burn
111.	S&B_MaxDryingPer	The latest time after slashing when fire can occur;	days	1 – 200 (30)	Management/ Slash and Burn
112.	S&B_MinDryingPer	The earliest time after slashing that fire can occur	days	0 – 100 (20)	Management/Slash and Burn
113.	S&B_NecroBurnFrac	Fraction of surface necromass burnt as a function of fire temperature.	dimensionless	(see table Slash&Burn)	Management/ Slash and Burn
114.	S&B_NutVolatFracN	Volatilization fraction of N in the burnt necromass,	dimensionless	(see table Slash&Burn)	(Slash&Burn)
115.	S&B_NutVolatFracP	Volatilization fraction of P in the burnt necromass,	dimensionless	(see table Slash&Burn)	(Slash & Burn)
116.	S&B_pHRecFrac	Daily recovery fraction of soil pH in the topsoil	fraction	0.001–0.1 (.01)	Management/ Slash and Burn

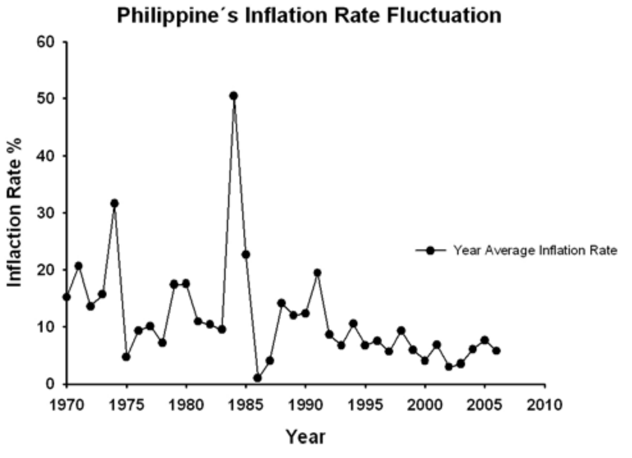
No	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link in Excel)
117.	S&B_PSorpRecFrac	Daily recovery fraction of the P_sorption in the topsoil from its post-fire towards its pre-fire value	fraction	0.001–0.1 (.01)	Management Slash and Burn
118.	S&B_Scorch WRemFra	Fraction of scorched wood removed after slash and burn event	fraction	0 – 1 (.3)	Management/ Slash and Burn
119.	S&B_SlashDOY	A graphical input tabulating day of year at which slashing is performed	Julian days	(see S&B_ graph)	Management/ Slash and Burn
120.	S&B_SlashYear	A graphical input tabulating year at which slashing is performed	dimensionless	any integer value (100)	Management/ Slash and Burn
121.	S&B_SOMBurnFrac	Fraction of all SOM pools in the topsoil (Layer 1) respired (C) or mineralized (N & P)	dimensionless	(see table Slash&Burn)	Management/ Slash and Burn
122.	S&B_SurfLitBurn Frac	Fraction of all surface litter respired (C) or mineralized (N & P)	dimensionless	(see table Slash&Burn)	Management/ Slash and Burn
123.	S&B_TimetoPileUp	Number of days between primary burn and for a secondary burn	days	1 – 100 (15)	Management/Slash and Burn
124.	S&B_TimetoWood Rem	Number of days between primary burn and removal of scorched wood	days	1 – 50 (10)	Management/Slash and Burn
125.	S&B_TTempTol [Tree]	Maximum fire temperature that a tree can tolerate.	^{0}C	40 – 90 (75)	(Tree Library/ Slash&Burn)
126.	S&B_WatRetRecFrac	Daily recovery fraction of soil water retention in the topsoil from its post-fire towards its pre-fire value	fraction	0.001 – 0.1 (0.005)	Management/ Slash and Burn
127.	S&B_Wetness TempImp	Fractional reduction in fire temperature per unit of moisture content of the fuel	fraction	0 – 1 (.5)	Management/ Slash and Burn
128.	S_C_RtStruc FormFrac	Fraction of contribution of crop root decay on root channels	fraction per m	(.1)	Soil Structure
129.	S_KsatHperV*i*	Ratio of saturated hydraulic conductivity in horizontal and vertical direction for layer *i*	dimensionless	0 – 5 (1)	Soil Structure/K Sat ratio
130.	S_KSatVDeepSub	Saturated hydraulic conductivity of the soil below layer 4,	cm day^{-1}	1 – 100 (20)	Soil Structure
131.	S_KStrucDecay	Relative rate of decay of the macropore structure,	day^{-1}	0 – 0.1 (.001)	Soil Structure
132.	S_RelWormLit*i*	Relative impact of 'worms' (soil fauna) on increase of saturated hydraulic conductivity in each layer	dimensionless	0 – 1 (1, 0.6, 0.3, 0.1)	Soil Structure
133.	S_RelWormSurf	Relative impact of 'worms' (soil fauna) increase of infiltration rate of the soil surface	dimensionless	0 – 1 (1)	Soil Structure
134.	S_SoilStructDyn?	Switch determining dynamics of soil structure	day^{-1}	0 or 1 (0)	Soil Structure
135.	S_SurfInfiltrDef [Zone]	Infiltration rate of soil surface in the absence of soil biological activity	mm day^{1}	25 – 10000 (25)	Soil Structure
136.	S_SurfInfiltrInit [Zone]	Infiltration rate of the soil surface at the start of the simulation	mm day^{1}	100 – 10000 (1000)	Soil Structure
137.	S_T_RtStrucForm Frac	Fraction of contribution of tree root decay on root channels	fraction per m	(.3)	Soil Structure
138.	S_WormsLikeLit Metab	Activity (in arbitrary units) of soil fauna per unit of organic inputs	m^2 kg^{-1}	0.00001 – 0.1 (.00001)	Soil Structure
139.	S_WormsLike LitStruc	Activity of soil fauna per unit of organic inputs	m^2 kg^{-1}	0.0000005 – 0.1 (.0000005)	Soil Structure

No	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link in Excel)
140.	S_WormsLike SOMMetab	Activity of soil fauna per unit of organic inputs	$m^2 kg^{-1}$	0.000001 – 0.1 (.000001)	Soil Structure
141.	S_WormsLike SOMStruc	Activity of soil fauna per unit of organic inputs	$m^2 kg^{-1}$	0.00000005 – 0.1 (.00000005)	Soil Structure
142.	T_ApplyPalm?[Tree]	Allocation of biomass to storage pool follows oil palm rule.	dimensionless	0 or 1 (0)	(Tree Library/Fruit)
143.	T_DOY 1 LfFlush[Tree]	Day of the first cycle of leaf flush	Julian days	1 – 365 (1)	Tree parameters
144.	T_DOY 2 LfFlush[Tree]	Day of the second cycle of leaf flush	Julian days	1 – 365 (400)	Tree parameters
145.	T_DOYSeaLitFall1 Start[Tree]	Day when the first season of leaf starts dropdown	Julian days	1 – 365 (400)	Tree parameters
146.	T_DOYeaLit Fall2Start[Tree]	Day when the second season of leaf starts dropdown	Julian days	1 – 365 (400)	Tree parameters
147.	T_DOY_Compl1 LfFall[Tree]	Day when the first season of leaf completely dropdown	Julian days	1 – 365 (400)	Tree parameters
148.	T_DOY_Compl2 LfFall[Tree]	Day when the second season of leaf completely dropdown	Julian days	1 – 365 (400)	Tree parameters
149.	T_FracSeaLitFall1 [Tree]	Fraction of tree canopy become litterfall	dimensionless	0 – 1 (1)	(Tree parameter/
150.	T_FruitAllocMax [Tree]	Allocation of biomass to fruit each day	$kg\ m^{-2}\ day^{-1}$	0 – 1 (0)	Management/ Harvesting
151.	T_FruitAllocStage [Tree]	Graphical input parameter as a function of tree stage	dimensionless	0 – 1	Management/ Harvesting
152.	T_FruitHarvFrac [Tree]	Harvest index for fruit. Constant value for every fruiting season	dimensionless	0 – 1 (0)	Management/ Harvesting
153.	T_GenLitFracMax [Tree]	Fraction of fruit will drop	dimensionless	0 – 1 (.05)	Management/ Harvesting
154.	T_GenLitStage [Tree]	Graphical input parameter as a function of tree stage	dimensionless	0 – 1	Management/ Harvesting
155.	T_GraphPhenol? [Tree]	Parameter governing an option to simulate tree phenology	dimensionless	0 or 1 (0)	Tree parameter
156.	T_KillDOY[Tree]	Schedule date, day of year to kill tree	Julian days	1 – 365 (1)	Management
157.	T_KillY[Tree]	Schedule date, year to kill tree	dimensionless	(1000)	Management
158.	T_MycMaxInf[Tree]	Fraction of tree roots infected by mychorrhiza for a soil layer	dimensionless	0 – 1 (.3)	Tree Library
159.	T_NutMobT[SiNut]	Relative rate of transfer, per unit root length density (cm cm-3)	$m^2\ day^{-1}$	0 – 0.02 (0)	Tree Library
160.	T_PrunDoY[Tree]	Schedule for date of pruning. Entered from WANULCAS.XLS	Julian days	1 – 365 (365)	(Tree Management)
161.	T_PrunFracC[Tree]	Fraction of canopy that gets pruned, for T_PrunType = 0.	dimensionless	0 – 1 (0)	Managements
162.	T_PrunFracC[Tree]	Fraction of tree canopy gets pruned, for T_PrunFrac? = 0	dimensionless	0 – 1 (1)	Management
163.	T_PrunFracD[Tree]	Fraction of tree canopy that gets pruned, for T_PrunFrac? = 1	dimensionless	0 – 1 (1)	(Tree Management)
164.	T_PrunHarvFracC [Tree]	Fraction of pruned canopy that harvested for T_PrunType?	dimensionless	0 – 1 (0)	Managements

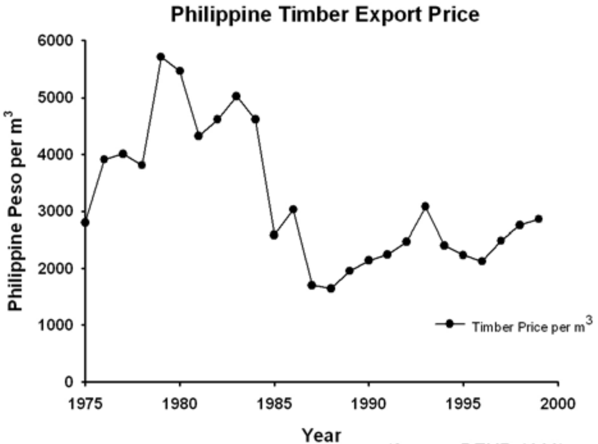
No	Acronym	Definition	Dimensions	Range of value (Default value)	Input Section (Link in Excel)
165.	T_PrunHarvFracD [Tree]	Fraction of tree pruned biomass harvested. Value changes overtime	dimensionless	0 or 1 (0)	Tree Management
166.	T_PrunLimit	Critical total LAI of all trees shadowing the crop zone, triggering a pruning event	dimensionless	0 – 5 (100)	Management/Pruning
167.	T_PrunPlant?[Tree]	Parameter governing pruning decision.	dimensionless	0 or 1 (1)	Management
168.	T_PrunRecov[Tree]	Time needed for tree to recover after pruning	days	0 – 30 (14)	Management
169.	T_PrunStageLimit [Tree]	The latest crop stage at which automatic pruning is still performed.	dimensionless	1 – 2 (1.8)	Management
170.	T_PrunType?	This parameter governs the type of pruning events.	dimensionless	0 (0 or 1)	Managements
171.	T_PrunWeight [Zone,Tree]	Input weight value governing amount of tree pruning going into each zone relative to other zones	dimensionless	0 – 10	Management
172.	T_PrunY[Tree]	Schedule for year of pruning. Entered from WaNuLCAS.XLS	dimensionless	(100)	(Tree Management)
173.	T_SlashLabour	Amount of labour involved in slashing the field per unit simulated filed as a function of biomass	person days	(see T_SlashLab graph)	Management/ Slash and Burn
174.	T_SlashSellWood Frac[Tree]	Indicates the fraction of wood that is removed from the plot at the time of slashing the vegetation	dimensionless	0 – 1 (0)	Management/Slash and Burn
175.	T_StageAftPrun [Tree]	Tree growth stage after pruning	dimensionless	0 – 2 (1)	Tree Library
176.	T_TranspRatioTime	Graphical input parameter as a function of tree stage that determine the dynamic of tree transpiration	-	-	Tree Parameter
177.	T_TreesperHa[Tree]	Tree plant density	dimensionless	any integer value (400)	Tree Parameters
178.	T_WoodFracH Remain	Wood height remains after pruning.	m	0-100 (100)	Management
179.	T_WoodHarvDOY [Tree]	Schedule for date of pruning. Entered from WANULCAS.XLS	Julian days	1 – 365 (364)	(Tree Management)
180.	T_WoodHarvFrac [Tree]	Fraction Harvested wood	dimensionless	0 – 1 (.95)	Management/Timber Harvesting
181.	T_WoodHarvY[Tree]	Schedule for year of timber harvesting.	dimensionless	Any integer value (100)	(Tree Management)
182.	W_Hyd?	Parameter governing water hydraulic lift application in model.	dimensionless	0 – 1 (0)	Soil Water and Nutrient

ANNEX 5: PAM ANALYSIS EXAMPLE

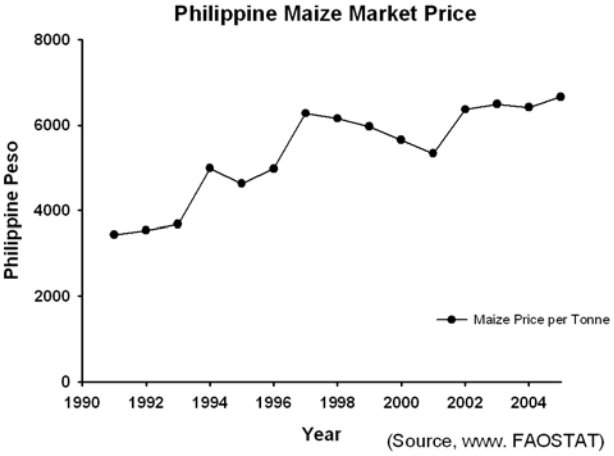
1. MACROECONOMIC BASED INFORMATION



(Source, www. census.gov.ph)



(Source, DENR 1999)



(Source, www. FAOSTAT)

2. EXAMPLE OF PAM PROFITABILITY CALCULATIONS

Input/output data per year for Scenario-1: Maize Moncropping:

I / O		**Y-1**	**Y-2**	**Y-3**	**Y-4**	**Y-5**	**Y-6**	**Y-7**	**Y-8**	**Y-9**	**Y-10**	**Y-11**	**Y-12**	**Y-13**	**Y-14**	**Y-15**
INPUT	**Unit**															
Urea	kg/ha	196	196	196	196	196	196	196	196	196	196	196	196	196	196	196
TSP	kg/ha	133	133	133	133	133	133	133	133	133	133	133	133	133	133	133
Seed Maize	S/ha	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
Seedling	SL/ha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LABOR																
SAB	PS/ha	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Plowing	PS/ha	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Plant-Maize	PS/ha	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Plant-Trees	PS/ha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Weeding	PS/ha	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16
Fert-Maize	PS/ha	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Harv-Maize	PS/ha	13	18	17	16	16	15	15	15	15	15	15	15	15	15	15
Harv-Trees	PS/ha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OUTPUT																
Maize grain	kg/ha	3,3	4,5	4,2	3,9	3,8	3,8	3,7	3,7	3,7	3,7	3,7	3,6	3,6	3,6	3,7
Timber	m3/ha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Farm-level budget per year for Scenario-1: Maize Moncropping

BUDGET		**Y-1**	**Y-2**	**Y-3**	**Y-4**	**Y-5**	**Y-6**	**Y-7**	**Y-8**	**Y-9**	**Y-10**	**Y-11**	**Y-12**	**Y-13**	**Y-14**	**Y-15**
INPUT	**Unit**															
Urea	Php/ha	3,530	3,530	3,530	3,530	3,530	3,530	3,530	3,530	3,530	3,530	3,530	3,530	3,530	3,530	3,530
TSP	Php/ha	2,074	2,074	2,074	2,074	2,074	2,074	2,074	2,074	2,074	2,074	2,074	2,074	2,074	2,074	2,074
Seed-Maize	Php/ha	267	267	267	267	267	267	267	267	267	267	267	267	267	267	267
Seed-Trees	Php/ha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LABOR																
SAB	Php/ha	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700
Plowing	Php/ha	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000
Plant-Maize	Php/ha	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
Plant-Trees	Php/ha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Weeding	Php/ha	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600	1,600
Fert-Maize	Php/ha	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400
Harv-Maize	Php/ha	1,322	1,811	1,704	1,576	1,555	1,531	1,514	1,505	1,492	1,484	1,488	1,473	1,470	1,472	1,488
Harv-Trees	Php/ha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OUTPUT																
Maize grain	Php/ha	22,045	30,190	28,417	26,272	25,934	25,532	25,248	25,093	24,877	24,743	24,816	24,566	24,507	24,545	24,809
Timber	Php/ha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Cash-flow for social prices conditions. Scenario-1: Maize Moncropping:

CASH-FLOW	**Unit**	**Y-1**	**Y-2**	**Y-3**	**Y-4**	**Y-5**	**Y-6**	**Y-7**	**Y-8**	**Y-9**	**Y-10**	**Y-11**	**Y-12**	**Y-13**	**Y-14**	**Y-15**	**Total**	**NPV**
Total Rev.	Php ha	22,045	30,190	28,417	26,272	25,934	25,532	25,248	25,093	24,877	24,743	24,816	24,566	24,507	24,545	24,809	381,594	253,639
Total Cost	Php ha	17,893	18,382	18,275	18,147	18,126	18,102	18,085	18,076	18,063	18,055	18,059	18,044	18,041	18,043	18,059	271,451	179,356
Cost inputs	Php ha	5,871	5,871	5,871	5,871	5,871	5,871	5,871	5,871	5,871	5,871	5,871	5,871	5,871	5,871	5,871	88,067	58,156
Cost labour	Php ha	12,022	12,511	12,404	12,276	12,255	12,231	12,214	12,205	12,192	12,184	12,188	12,173	12,170	12,172	12,188	*183,384*	121,200
Ret Land	Php ha	4,152	11,809	10,141	8,125	7,808	7,429	7,162	7,017	6,814	6,688	6,757	6,522	6,466	6,502	6,750	110,143	74,283
Total Labor	PS ha/yr	120	125	124	123	123	122	122	122	122	122	122	122	122	122	122	1,834	
Ret Labor	Php/day																	161

Cash-flow for private prices conditions. Scenario-1: Maize Moncropping:

CASH-FLOW	**Unit**	**Y-1**	**Y-2**	**Y-3**	**Y-4**	**Y-5**	**Y-6**	**Y-7**	**Y-8**	**Y-9**	**Y-10**	**Y-11**	**Y-12**	**Y-13**	**Y-14**	**Y-15**	**Total**	**NPV**
Total Rev.	Php ha	22,045	30,190	28,417	26,272	25,934	25,532	25,248	25,093	24,877	24,743	24,816	24,566	24,507	24,545	24,809	381,594	181,109
Total Cost	Php ha	17,893	18,382	18,275	18,147	18,126	18,102	18,085	18,076	18,063	18,055	18,059	18,044	18,041	18,043	18,059	271,451	127,437
Cost inputs	Php ha	5,871	5,871	5,871	5,871	5,871	5,871	5,871	5,871	5,871	5,871	5,871	5,871	5,871	5,871	5,871	88,067	41,303
Cost labour	Php ha	12,022	12,511	12,404	12,276	12,255	12,231	12,214	12,205	12,192	12,184	12,188	12,173	12,170	12,172	12,188	*183,384*	86,134
Ret Land	Php ha	4,152	11,809	10,141	8,125	7,808	7,429	7,162	7,017	6,814	6,688	6,757	6,522	6,466	6,502	6,750	110,143	53,672
Total Labor	PS ha/yr	120	125	124	123	123	122	122	122	122	122	122	122	122	122	122	1,834	
Ret Labor	Php/day																	163

NPV-PAM-RESULTS (Php ha-1)

SCENARIO 1. Continuous Maize monocropping with fertilizer

	Income	Cost		Profits
		Inputs	*Labour*	
Private prices	181,109	41,303	86,134	53,672
Social prices	253,639	58,156	121,200	74,283
Effects of divergences	**-72,530**	**-16,853**	**-35,066**	**-20,611**

3. EXAMPLE OF SENSITIVITY ANALYSIS TO MACROECONOMIC CHANGES

PAM profitability results to all agricultural systems at present conditions (Spet. 2006)

Agricultural System	**Private Conditions**		**Social Conditions**	
	Returns to Land (Php)	**Returns Labour (Php/ Work-day)**	**Returns to Land (Php)**	**Returns Labour (Php/Work-day)**
Maize Monoculture	53,672	163	74,283	161
100 *S. contorta*	44,248	153	72,997	163
100 *V. parviflora*	47,032	157	94,571	182
100 *P. indicus*	50,937	161	98,445	184
100 *S. macrophylla*	97,679	181	164,849	249
200 *S. contorta*	37,060	147	77,297	171
200 *V. parviflora*	54,015	179	148,699	265
200 *P. indicus*	58,853	174	143,637	228
200 *S. macrophylla*	54,536	169	180,937	257
400 *S. contorta*	37,633	149	77,376	168
400 *V. parviflora*	52,405	178	171,091	294
400 *P. indicus*	65,299	181	192,134	269
400 *S. macrophylla*	64,895	181	223,819	299
800 *S. contorta*	34,708	175	118,892	307
800 *V. parviflora*	48,845	196	217,484	437
800 *P. indicus*	59,825	196	258,733	414
800 *S. macrophylla*	81,979	250	319,215	554

PAM labour requirement results for each land use system at present conditions (Spet. 2006)

		Labour Requirements (Person-day-ha^{-1})			
Tree density	Maize Monocropping	*S. contorta* intercrop	*V. parviflora* intercrop	*P. indicus* intercrop	*S. macrophylla* intercrop
0	1834	0	0	0	0
100	0	1,741	1,732	1,761	1,744
200	0	1,677	1,246	1,694	1,671
400	0	1,649	1,225	1,735	1,717
800	0	765	869	1,162	960

Sensitivity analysis responds to discount rate

Land-use system	**Profitability (Php. ha^{-1}) (at social prices)**			**Elasticity (%) to d.r. (*E = % change in x / % change in y*)**		
	d.r.=5.7	**d.r.=11.4**	**d.r.=17.1**	**System**	**Tree**	**Crop**
Maize-Monoculture	74,283	53,672	40,951	13.9	0.0	13.9
100 *S. contorta*	72,997	49,213	36,410	16.3	30.7	11.6
100 *V. parviflora*	94,571	60,161	42,708	18.2	28.2	4.4
100 *P. indicus*	98,445	63,680	45,489	17.7	28.8	11.7
100 *S. macrophylla*	180,937	97,679	59,076	23.0	27.6	9.5
200 *S. contorta*	77,297	47,727	33,019	19.1	29.8	7.1
200 *V. parviflora*	148,699	81,035	49,674	22.8	28.2	5.7
200 *P. indicus*	143,637	80,750	71,532	21.9	28.4	10.9
200 *S. macrophylla*	164,849	86,566	50,857	23.7	28.0	4.4
400 *S. contorta*	77,376	44,572	28,722	21.2	32.1	7.9
400 *V. parviflora*	171,091	87,621	49,803	24.4	28.7	4.1
400 *P. indicus*	192,134	100,150	57,665	23.9	28.7	10.6
400 *S. macrophylla*	223,819	111,271	60,514	25.1	28.3	5.8
800 *S. contorta*	118,892	60,547	34,628	24.5	27.6	1.0
800 *V. parviflora*	217,484	109,130	60,585	24.9	27.5	4.5
800 *P. indicus*	258,733	128,889	70,666	25.1	27.4	4.8
800 *S. macrophylla*	319,215	153,032	79,625	26.0	27.4	0.9

Sensitivity analysis responds to changes on Maize and Timber prices

Land-use system	Profitability (Php. ha^{-1}) (at social prices)			Elasticity (%) to prices (E = % change in x / % change in y)	
	Sept-06 Prices	2x Maize Price	2x Timber Price	Maize price	Timber price
Maize-Monoculture	74,283	399,059	74,283	219	0
100 *S. contorta*	72,997	296,504	94,827	153	15
100 *V. parviflora*	94,571	302,884	152,301	110	31
100 *P. indicus*	98,445	332,472	135,801	119	19
100 *S. macrophylla*	180,937	395,947	318,717	59	38
200 *S. contorta*	77,297	273,806	124,204	127	30
200 *V. parviflora*	148,699	314,399	267,513	56	40
200 *P. indicus*	143,637	358,072	239,923	75	34
200 *S. macrophylla*	164,849	354,608	305,693	58	43
400 *S. contorta*	77,376	272,281	131,782	126	35
400 *V. parviflora*	171,091	322,052	325,945	44	45
400 *P. indicus*	192,134	403,861	345,385	55	40
400 *S. macrophylla*	223,819	415,471	427,745	43	46
800 *S. contorta*	118,892	204,669	232,513	36	48
800 *V. parviflora*	217,484	323,811	419,415	24	46
800 *P. indicus*	258,733	394,043	499,266	26	46
800 *S. macrophylla*	319,215	425,543	631,655	17	49