Contents

1 Introduction and scope

In recent years variety of successional forestry and agroforestry schemes have been promoted and implemented in tropical and subtropical regions in order to make better use of resources, increase system resilience, mitigate environmental impacts of resource use and/or increase farmers' income (e.g. HART 1980, EWEL 1999, COICAP 1999, MILZ 2001). In the Philippines as one of the most severely deforested countries worldwide (KUMMER & TURNER 1994), conservation of tree biodiversity is another important objective of such systems.

In the mid-1990s, the official Philippine reforestation scheme based on few fast-growing exotic tree species was contrasted with a more diversified planting system. Reintroducing high diversity of indigenous trees in dense multi-storey structure, a so-called *high-density closed canopy* system was developed (MARGRAF & MILAN 1996). Focus of this approach was clearly on conservation related to indigenous timber trees, mainly of the Dipterocarpaceae family. Later, more importance was given to profitability of the system, especially during the critical first years after planting, and fruit trees were assigned higher priority. Another step towards rentability could be taken through the participation in Clean Development Mechanism (CDM) projects, which reward carbon sequestration through reforestation.

For this study high-density closed canopy plots planted 1993-6 as well as a new plot (installed 2004) were surveyed in order to assess:

1. how site conditions (canopy closure, slope position and selected soil parameters) influence mortality and biomass production of trees and crops during the crucial first years after installation; for this purpose inventories, biomass measurements, PAR measurements and soil analyses were conducted on the 2004 plot;

2. how the trees influence selected soil parameters: For this research question a paired plot approach comparing the >10-year old *high-density closed canopy* plots to adjacent fallowed land and classical reforestation was chosen. Soil parameters were selected, that are supposed to indicate short- to mid-term changes in land-use;

3. if amounts of sequestered CO_2 could make reforestation an option for CDM funding especially during the economically critical first years after planting. To assess this, biomass growth and carbon contents of the new plot as well as in fallowed plots were extrapolated to subsequent years using a computer model and validating results with existing inventories of *high-density closed canopy* plots.

1.1 Study area

1.1.1 Geography

Among the more than 7.000 Philippine islands, Leyte is situated in the Centre-East Visayas archipelago. The Visayas are delimited by Luzon in the North, Mindanao in the South, Palawan to the West and the Pacific Ocean to the East (fig.1). They are divided into three administrative units: Western Visayas, comprising Panay and Negros Occidental, Central Visayas with Negros Oriental, Bohol and Cebu, and Eastern Visayas (or Region VIII) with Leyte, Samar and Biliran as main islands.

Leyte island is situated at 9°55' to 11°48' N and 124°17' to 125°18' E. North-South extension is roughly 200km, distance from West to East ranges from 60km (between Tacloban and Palompon) to about 25km (Baybay to Abuyog). Total land area of Leyte is 762.178ha (NAMRIA, 2003). The island is divided into two administrative regions, Leyte with Tacloban, and Southern Leyte with Maasin as capital. Other commercial centres of Leyte are Ormoc City and the town of Baybay on the Western coast (fig.2).

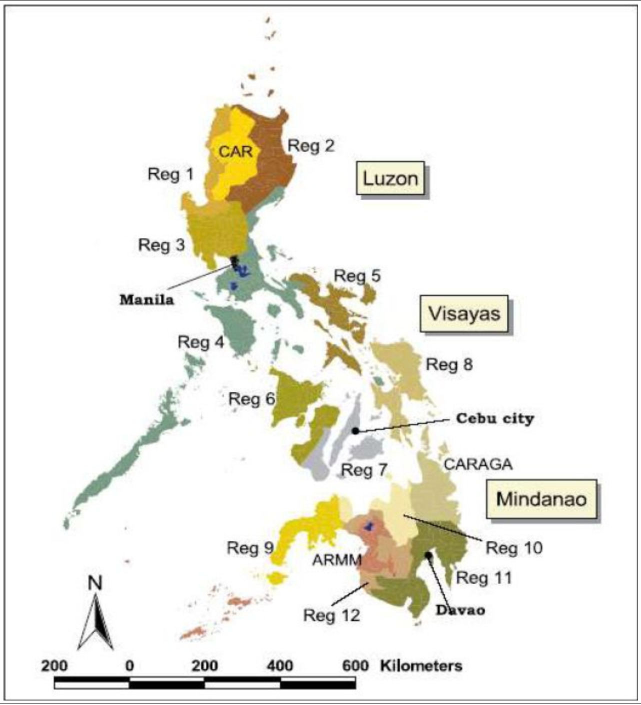

Figure 1: Administrative regions of the Philippines (Chokkalingam et al. 2006)

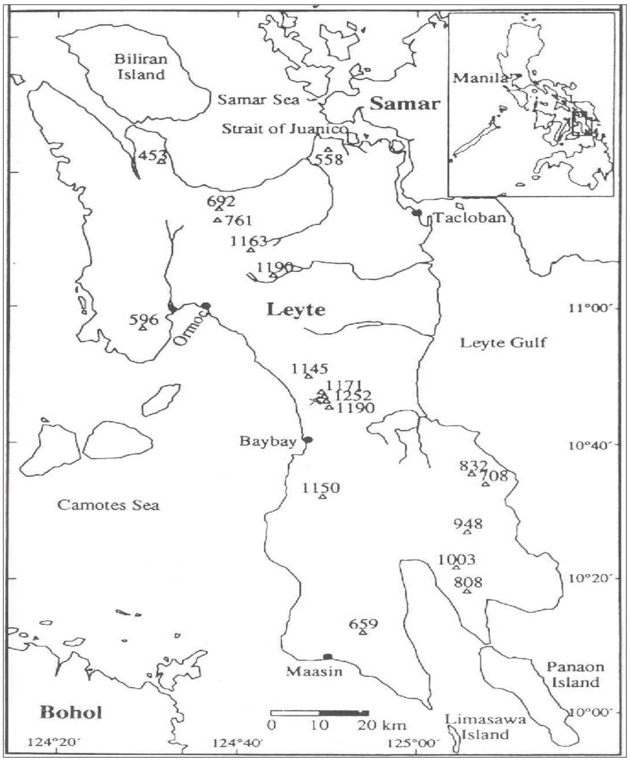

Figure 2: Leyte island, geography

Baybay municipality, where most of the research sites are located, is situated in the Centre West of Leyte, characterised by its position between the Camotes Sea to the West and the steep slopes of the Cordillera Central to the East. Some of the highest peaks like Mt. Pangasugan and Mt. Emik rise up to more than 1200m asl within a distance of less than 10km from the coast. As an administrative unit, Baybay is bordered by the municipalities of Albuera and Burauen to the North, Javier, Abuyog and Mahaplag to the East and Inopacan to the South.

1.1.2 Geology, geomorphology and soils

1.1.2.1 Tectonics and stratigraphy

As a result of plate tectonic movements, the Eastern and Western margins of the Pacific were and still are subject to strong volcanic and seismic activities. Where the Eurasian and Pacific tectonic plates collide from Alaska through Kamchatka and Japan to the Philippines and Indonesia, intense volcanic activity has influenced the formation of terrestrial surfaces since the tertiary (SANTOS & RAMOS 1995). Within the Philippine archipelago, the Philippine Sea Plate from the East and the Eurasian Plate from the West subduct beneath the Philippine Mobile Belt, which is uplifted (ZANG & NING 2002). Along the subduction zones trenches and troughs were formed: During early Miocene the Manila Trench originated from a subduction of the Eurasian Plate under the Philippine Mobile Belt (SANTOS & RAMOS 1995)[1]. The Philippine Trench, extending along the Eastern margin of the Philippine territory from Luzon through Samar and Leyte to Mindanao, was formed during the Pliocene.

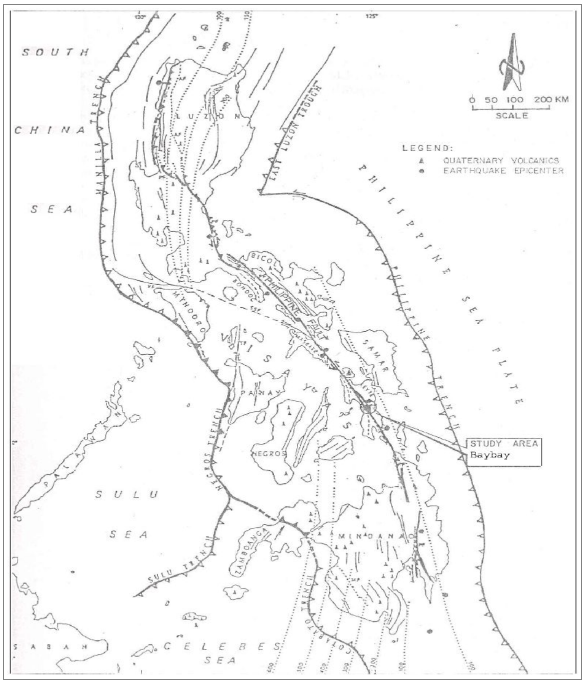

Figure 3: Tectonic plates and trenches in the Philippines (SANTOS & RAMOS 1995)

In the course of the tectonic processes which led to the formation of the Manila and (later) the Philippine Trench, a fault line broke up parallel to the latter. This Philippine Fault Line crosses the entire Philippine archipelago for approx. 1200km in a NNW-SSE course (fig. 3).

Coming from the North, the fault line enters Leyte island near Biliran Strait. As its formation was closely related to upfolding processes (BARRIER 1991, after SANTOS & RAMOS 1995), the fault line coincides with or parallels the ridges of Leyte's central mountain range, the so-called Leyte Cordillera.

North of Ormoc the fault line splits up into at least three parallel lines which form a pull-apart zone of 60km length. Within this tensional block the highest volcanic activity occurred during the Miocene. Some of the formerly most active volcanoes (Alto Peak, Mt. Lobi, Mt. Mahagnao) are situated here and at present geothermal energy is extracted in the Greater Tongonan Area. Further south at least two fault lines cross each other North-east of Baybay town, before they finally separate into three and travel along both sides of Sogod Bay and Cabalian Bay (ANONYMOUS 1993).

In contrast to the tectonic movement around the Manila Trench, which has almost come to a halt (SANTOS & RAMOS 1995), the Philippine Fault Line is still in motion. During an observation period from 1991-2002, BACOLCOL, BARRIER & DUQUESNOY (2004) measured an annual displacement rate of 2.3-3.6cm. Main structural processes in Central Leyte's fault zone, East-West compression and wrench faulting, are still going on (PANEM 1992). The

1 According to YUMUL ET AL. (2003) a collision of the Palawan microcontinental block with the Philippine Mobile Belt caused a rotation of Luzon, which then onramped the South China Sea Plate.

resulting tensions are absorbed by slipping and seismic activities close to the fault zone (Bacolcol, Barrier & Duquesnoy 2004).
The Philippine Fault Line divides Leyte into two geologically different rock formations: To the West, the Central Philippine Arc Terrane (CPAT) consists of a sedimentary basement superimposed by volcanic layers, which are interrupted by marine sediments. To the East the East Luzon-Samar-Mindanao Disrupted Terrane (ELSMDT), based on metamorphites, is more heterogeneous and contains limestone, clastic sediments, volcanic and metamorphic elements. Both are divided by the Burauen Graben, but have been amalgamated.
Historically, in Leyte province a pre-oligocene basement complex of amalgamated ultramafic and metamorphic rocks was overlaid by marine sediments until early to middle miocene (Aquino et al. 1983). Volcanism then lead to folding, intrusions, extrusions and volcanic flows until the Pleistocene; thus porphyric and dacitic layers alternate with sedimentary sequences (Bayrante 1982). After the quarternary recession of the sea, mainly sedimentary deposits like siltstone and conglomerates (Aquino et al. 1983) were left behind. In the following, calc-alkaline volcanics and intrusives dominated (Santos & Ramos 1995); pyroclastic flows composed of a crystal-vitric tuff matrix containing pumice and andesitic material (Bayrante 1982) constitute the parent material of many volcanic soils in the area. Other important components are calcareous rocks and breccia. Once volcanism had ceased, weathering and erosion became the dominating factors for land formation and in recent times alluvial depositions accumulated in the lowlands and river deltas (Aquino et al. 1983).

1.1.2.2 Surface geology

Surface geology along Leyte Cordillera is determined by volcanic constituents of miocenic origin like basaltic and andesitic materials, partly covered by younger (pliocenic) conglomerates and pyroclastics and – in the outer zones – by quarternary volcanic ashes (Jahn & Asio 1998). This also applies to the study area: The western foothills and mountain slopes of the cordillera developed from intermediate basaltic volcanoclastics (Jahn & Asio 1998), which cover the miocenic *Burauen volcanics* (andesites, dacitic flows and basalt). The latter form the geological surface on the east side of the mountains.
South of Baybay, coralline limestone and volcanic sediments alternate on a small scale. Further south, coralline limestone dominates (fig.4). The eastern and north-eastern regions as well as Ormoc Valley and the western coastal areas are characterised by holocene alluvial lowlands extending towards the footslopes of the Cordillera. On the very north-easterly tip of the island, bordering Samar, a cretaceous mountain complex represents the oldest geological formation in Leyte.

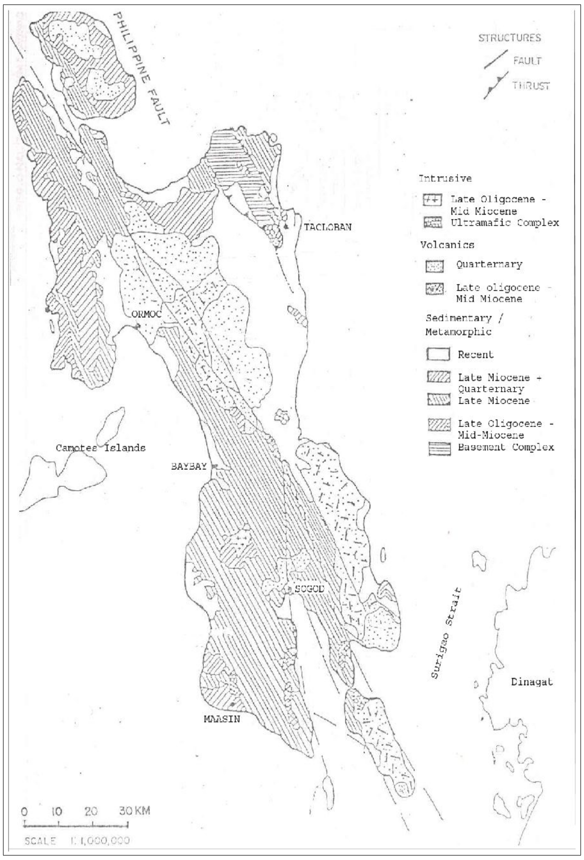

Figure 4: Geology of Leyte (Santos & Ramos 1995)

1.1.2.3 Present landforms

The central cordillera traverses Leyte island along the Philippine Fault Line from NNW to SSE, its highest elevation, Alto Peak, reaching more than 1300m asl (Jahn & Asio 1998). Some of the highest summits in Baybay municipal district like Mt. Pangasugan with its almost vertical slopes can be seen from all study sites on the West coast between Marcos and Patag. These mountains rise up to more than 1100m asl within a distance of merely 5-6km from the coastline (Bureau of Coast and Geodetic Service 1982). Valleys are generally V-shaped in the upper parts of this central portion of the cordillera. The deep valleys and deeply weathered saprolites in the lower parts have been interpreted as indicators for long-lasting erosion processes (Jahn & Asio 1998). As a consequence of the rugged relief and heavy rains, erosion and landslides are dominating natural processes in this landscape[2]. In front of the central mountain range, foothills and isolated plateaus spread half way to the coastline.

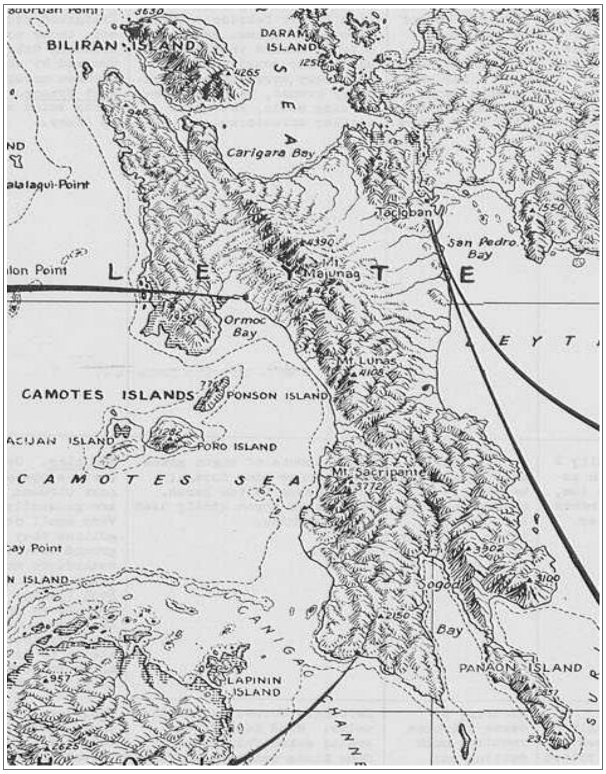

Figure 5: Topography of Leyte

Southwards from Pagbanganan River, which discharges in Baybay city, mountain elevations decrease gradually and landscape forms are more gentle due to their limestone origin. Maitum and Punta study sites are located in this area, where calcareous and volcanic materials coexist. Further south, coralline Karst dominates the landscape (see fig.5). To the east of the Cordillera, the mountain spurs bottom out into an extensive lowland plain that finally reaches the Pacific coast. The north-eastern part of Leyte, too, is dominated by alluvial lowland plains with the exception of a mountain group at the very tip, where Leyte faces Samar island.

1.1.2.4 Soils

<u>Soil forming processes</u>: Among the soil forming factors – parent material, organisms, topography, climate (Birkeland 1999) and time (Lavelle & Spain 2005) – the first factor geologically subdivides Leyte soils into calcareous and volcanic regions.

High temperatures and humid climate are strong driving factors for soil formation particularly in well-drained tropical soils, where they accelerate mineralisation, weathering of the parent material, leaching and loss of bases, resulting in acidification, desilification (leading to a relative accumulation of Fe- and Al-sesquioxides) and formation of hematite.

For the formation of the different clay minerals as well as for the sesquioxides, according to Asio (1996), drainage of the soil (in other words: residence time of the weathering solution) plays a key role. In his mineralogic research on an Andosol – Alisol catena in Western Leyte, Asio found that both profiles developed from basalt composed of plagioklase feldspars and pyroxene as most important minerals with lower concentrations

2 In many cases exacerbated by kaingin, the local slash-and-burn land use practice.

of magnetite. These main components are easily weatherable (due to their narrow SiO_2/Al_2O_3-ratio, s. Birkeland 1999) under humid tropical conditions. Weathering of the Andosol's pyroxene and plagioklase finally led to the formation of halloysite and kaolinite, secondary two-layer lattice silicates (Jahn & Asio 1998) in the present Alisol. Besides these low-activity clays, goethite, hematite and quartz make up for most of the mineral compounds.
On the other hand, upland soil formation does oftenly not take place *in situ* and many soils are still genetically immature. This is due to the steep slopes in the geologically young landscape, which make erosion and landslides – at least on volcanic rock and intensified by human influence – important soil forming factors (Asio 1996). As an example of ancient natural erosion, Jahn & Asio (1998) mention the remaining deeply weathered saprolitic peneplains west of the cordillera with their deep valleys. On a smaller scale and partly man-made, effects of erosion can be observed in most upland areas including the research sites, with colluvial material superimposed to the original soil.
Moreover, many lowland soils with gleyic properties are still immature, because soil formation is impeded by waterlogging (Asio 1996).
Relocation of material *within* the soil profile is also characteristic for Leyte soils and can be observed as clay accumulation in argillic horizons[3]. Yet, although most of the uphill soils in Leyte are well-drained (Barrera et al. 1954), ferralitic soils can only be found on some plateaus and hills with little colluvial influence, where soil genesis has taken place *in situ*. In some places soil profiles are divided into a colluvial brownish upper and a lower reddish zone. Due to the young geological age, weathering of the parent material has not progressed profoundly, which mitigates the effects of leaching: In spite of progressing acidification, contents in basic cations are still relatively high in most Leyte soils due to reserves still present in the minerals (Jahn & Asio 1998).
Investigating an Andosol – Alisol catena on Leyte's West Coast, Asio (1996) identified humus accumulation, loss of bases, acidification, braunification, clay formation and desilification/ferralitisation as main driving processes for soil genesis. Among this study's experimental sites, humus accumulation was observed mainly in calcareous soils; although these are biologically very active (Daub 2002), drought as a consequence of excessive drainage might impede mineralisation of humus to some extent.
<u>Distribution of soils</u>: Compared to other tropical regions, many South-east Asian soils are relatively young and there is still a considerable share of soils rich in basic cations (such as Luvisols). Yet many Philippine upland soils are already depleted in basic cations due to their advanced stage of development, if for example an Andosol – [Luvisol[4] /] Alisol – [Acrisol] chronosequence is assumed[5] (s. Asio 1996). According to the FAO Soil Map of the World, most soils in the Philippines are Acrisols, followed by Cambisols and Luvisols (see table 1). For hilly soils, Acrisols cover the largest portion with more than 5 million ha, Luvisols, Cambisols and Andosols follow with less than 500.000ha each (FAO Gateway).

3 On the other hand, Asio (1996) suggests that in some volcanic Baybay soils clay formation took place in situ.
4 meaning that they have CEC of >24cmolC /kg clay distinguishing them from Acrisols. Alisols also have high CEC, but base saturation of < 50% and additionally alic properties within the major part between 25 to 100cm depth.
5 Asio (1996) concludes from rock and soil samples of a representative Baybay Alisol developed from basalt, that this soil has already lost 90% of its original content of basic cations and 85% of the initial P_2O_5.

Table 1: FAO soil types in the Philippines (FAO Gateway for Land and Water Information)

Soil Types	Area (ha)
Acrisols	12,596,447
Cambisols	8,680,048
Luvisols	3,816,680
Fluvisols	599,450
Andosols	559,114
Gleysols	401,409
Nitisols	300,439
Regosols	224,404
Kastanozems	216,461
Arenosols	209,748
Phaeozems	52,472

Originally, soils in Leyte were classified according to suitability for agriculture, the main criterion being drainage. The classical soil survey by Barrera et al. (1954) distinguishes poorly, moderately and well-drained flat lowlands on one hand and well-drained rolling uplands on the other, independently of calcareous or non-calcareous underground. Each of these classes was divided into subtypes describing texture and locality (e.g. *Maasin clay*, *Pawing fine sandy loam* or simply *rough mountainous land*).

For western Leyte, the FAO Soil Map shows Acrisols, Luvisols and Cambisols as main soil groups (Ultisols and Alfisols in fig.6). A typical toposequence of volcanic origin could consist of Ochric Andosols (highest elevations), Orthic Acrisols and Luvisols down the slopes of the Cordillera, and Gleyic or Eutric Cambisols in the alluvial lowlands. For the lower mountains and hills, which are relevant for reforestation, Alisols and Cambisols have also been described besides the dominant Acrisols and Luvisols; soils on calcareous rock have been classified as Humic Acrisols (FAO), Phaeozems (Daub 2002) and Cambisols.

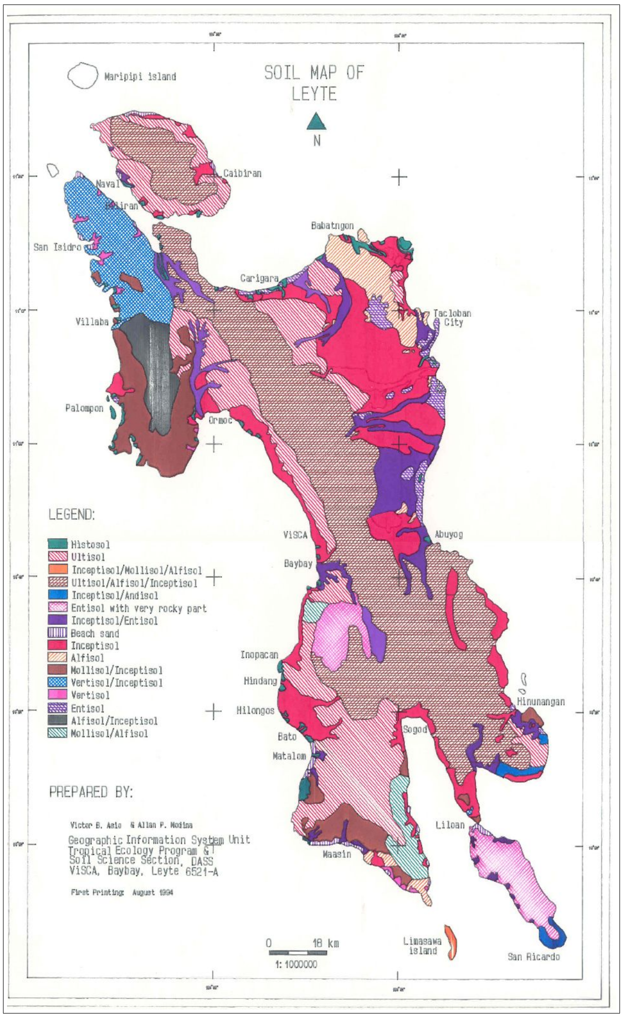

Figure 6: Soils of Leyte (Asio & Modina 1994)

<u>Ecological evaluation of upland soils in western Leyte</u>: To date only few soils in western Leyte have been studied in depth. Volcanic soils in the area are generally acidic in reaction and low in bulk density. Asio's research (1996) on a Haplic Alisol[6] near LSU showed, that soil physical parameters (rooting depth, rootability, drainage, water and air capacity) were favourable for plant growth but to some extent attenuated by the soil's supposedly high erodibility. Among soil chemical parameters the main constraints were P and to some extent available K, whereas availability of Ca and Mg was not limiting for plant growth (Asio et al. 1998).

6 This soil has been classified as Alisol by Asio, Daub and Zöfel due to its argic B, CEC > 24cmol$_c$/kg and base saturation < 50%. No analysis was conducted to determine, whether the soil meets FAO requirement for alic properties (> 60% Al^{3+} of CEC) in the major parts between 25 and 100cm depth.

Sesquioxides, humic substances and low activity clay minerals were the main reasons for the high phosphorus retention in the Alisol which has been observed to an even higher degree in Baybay Andosols by ZIKELI (1998). Other limiting factors in these Andosols were low base saturation and CEC. On the other hand, physical structure of Andosols was found to be excellent as long as rooting depth was sufficient (ASIO 1996; ZIKELI 1998).
A soil on coralline limestone on the study site in Punta (approx. 5km south of Baybay) was classified as Calcaric Phaeozem by DAUB (2002). It is characterised by a Mollic A horizon and a shallow A_H -BC profile and, according to FAO, must not contain secondary $CaCO_3$ within the upper 100cm.
Many upland soils in Leyte with exception only of the steepest mountainous parts are degraded as originally forested land has been converted to other land uses decades ago (s. 2.1.6). ASIO (1996) identified changes in soil colour and structure, reduced thickness of A_H and AB horizons as consequence of erosion, increased bulk density, reduced pore volume and aggregate stability caused by compaction, lower contents in humus and reduced soil respiration as indicators for past land clearing. Strategies to rehabilitate these soils include soil and canopy cover to enhance interception, transpiration and evaporation and thus reduce leaching, and tight nutrient cycles through diversified planting design.

1.1.3 Climate

Seasons in the Philippines are mainly determined by wind and rainfall patterns as temperatures do not vary strongly. Three phenomena exercise most influence on the archipelago during the transcourse of the year (after ARAKAWA 1969; NIEUWOLT 1977):

- The humid north-east monsoon from Oct – Mar, which originates in polar regions and is deflected as it enters the Philippines in south Luzon and Samar, thus in Leyte the main wind direction is SSW-wards.
- North Pacific trade winds from changing directions occurring Mar – May, which carry dry air to Leyte, even at their lower boundaries.
- The southwest or summer monsoon *Habagat* during May – Sep, which is more humid than the NE monsoon at the time it originates in the Indian Ocean, but loses part of its moisture passing Palawan and the western Visayas before reaching Leyte.

Exposition and orographic lifting modify these general principles on a smaller scale: North and east exposed areas like e.g. Aparri, Legaspi (NIEUWOLT 1977) and Tacloban (ASIO 1996) are subject to a typical east coast rainfall pattern with maxima coinciding with the NE monsoon, while in Manila (W exposure) and S or SE exposed regions rainfall distribution is inverse with a maximum during the SW monsoon. Despite this, entire Leyte (including the West coast) belongs to the first rainfall subtype.
CORONAS' (1920, as cited by ARAKAWA 1969) classification is based on rainfall patterns, dividing Leyte into two climatic zones east and west of the Cordillera. Both have in common, that there is no dry[7] month, and least amounts of rain fall in springtime. On the east side a pronounced rain maximum during NE monsoon by far exceeds precipitation of the cyclonic rains during summer.
The climate of western Leyte (Ormoc, LSU and Maasin) can be classified as Af according to KÖPPEN (1931), a rainforest climate with long-term mean temperature of the coldest month >18°C and precipitations of the driest month >60mm[8]. A so-called P_LO wind regime refers to regular-directional trade winds and summer monsoon. Climate data for LSU, Baybay, have been observed since the 1970s by the PAGASA network (see fig.7).

7 If monthly averages are considered
8 Subclassifications characterising minor dry periods - m or s'' – are not permitted for average monthly rainfall >60mm.

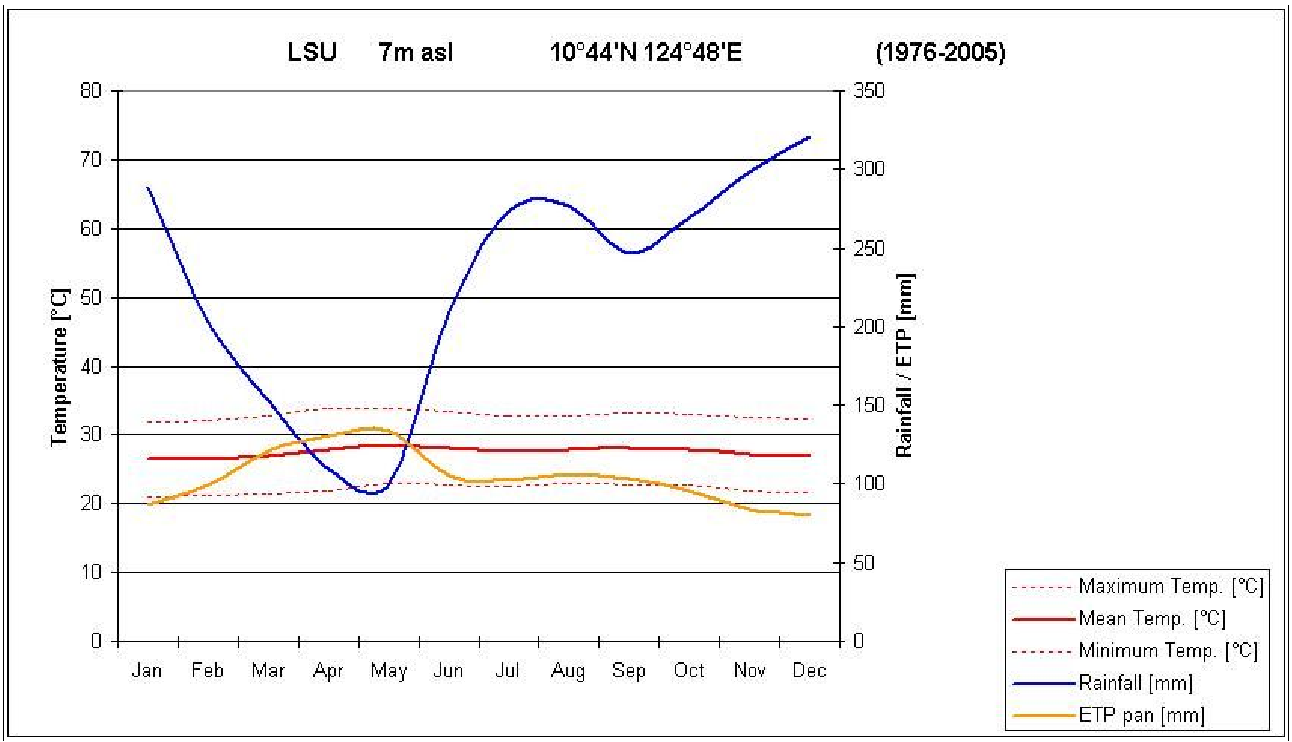

Figure 7: Climate chart (rainfall, pan evaporation, minimum, mean and maximum air temperatures) for LSU, Baybay, based on PAGASA data 1976 – 2005

Mean average temperature 1976-2005 was 27.5°C with monthly means varying only about 2°C, far below daily amplitudes as e.g. 10.9°C observed by BALZER (1994). Average total annual rainfall was 2748mm.

In many publications Baybay region is considered a humid area without any dry periods throughout the year. BALZER (1994) first questioned this standpoint: During Mar – May, monthly potential evapotranspiration can easily exceed rainfall indicating potential drought stress for plants. In addition, the monthly resolution usually depicted in climate charts does not show erratic rainfall with frequent dry periods of up to two weeks which, in a balance of monthly resolution, are compensated for by two or three heavy rains (see fig.9). During the period depicted in fig.8, for 63% of all days evaporation exceeded rainfall. In addition, during El Niño years precipitation would clearly fall below average values. As can be seen from fig. 7, 2004 was an exceptionally dry year, that received only 2317mm of rainfall compared to 3327mm in 2003 and 3159mm in 2005.

In spite of favourable physical properties of many soils in western Leyte (JAHN & ASIO 1998), those with very good drainage or shallow soils (especially on limestone), would under these conditions not hold enough water to supply plants[9]. Thus, dry seasons do occur from a plant physiological point of view. Phenological observations also show, that many native trees shed their leaves during the drier period in Mar – May.

9 Although, according to KÖPPEN (1931), at annual precipitation >2000mm, a dry season of up to 4 months would not have any long-term impact on natural vegetation.

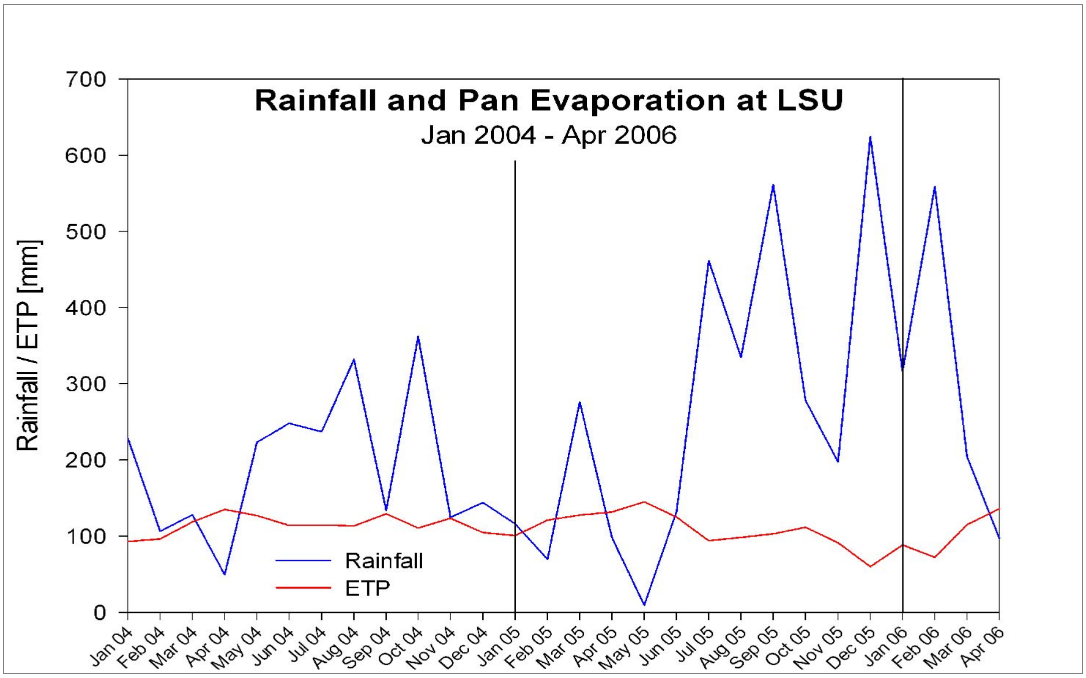

Figure 8: Precipitation and ETP for LSU Jan 2004- Apr 2006

In the perception of locals, seasons are more often linked to different wind regimes, like the wet Habagat monsoon. Typhoon season peaks from Aug to Sep, the Philippines being one of the most typhoon-prone regions in the world with an average of around 20 events per year (Arakawa 1969). These tropical storms can reach velocities of 10m/s as they reach the Philippines from the East. Some are deflected towards the North and streak the pacific side of the archipelago from Samar to NE Luzon. Others pass straight westward mainly through Samar and SW Luzon. Although Leyte's west coast is relatively sheltered by the mountain range and Baybay municipality is considered a non-typhoon-prone region, the area is affected by torrential rainfall brought along by typhoons which can cause flash floods and landslides[10].

Due to the extreme changes in landscape, weather data collected at PAGASA LSU (7m asl) need to be used with some caution for comparisons to the experimental site in Cienda, located 5km southeast from LSU and >100m asl. As an example, rainfall from end of May until beginning of July 2004 (onset of Westerly Habagat) was clearly higher at LSU and often did not even reach Cienda (fig. 9). Also during the dry season (Mar – May) Cienda is likely to receive less rain[11]. On the other hand, strong rainfall events are often caused by uprising air masses at the luff side of the Cordillera and tend to be more extreme in Cienda (examples May 14-16; June 8-9, June 14-16, July 26).

10 In 1991, heavy rain led to a landslide burying more than 5.000 inhabitants of Ormoc city, less than 50km north of the research area. In 2006, a similar disaster occurred in Guinsaugon, Southern Leyte.

11 which is not evident in fig. 8 due to a break-down of the rain gauge at Cienda from May 18-Jun 5

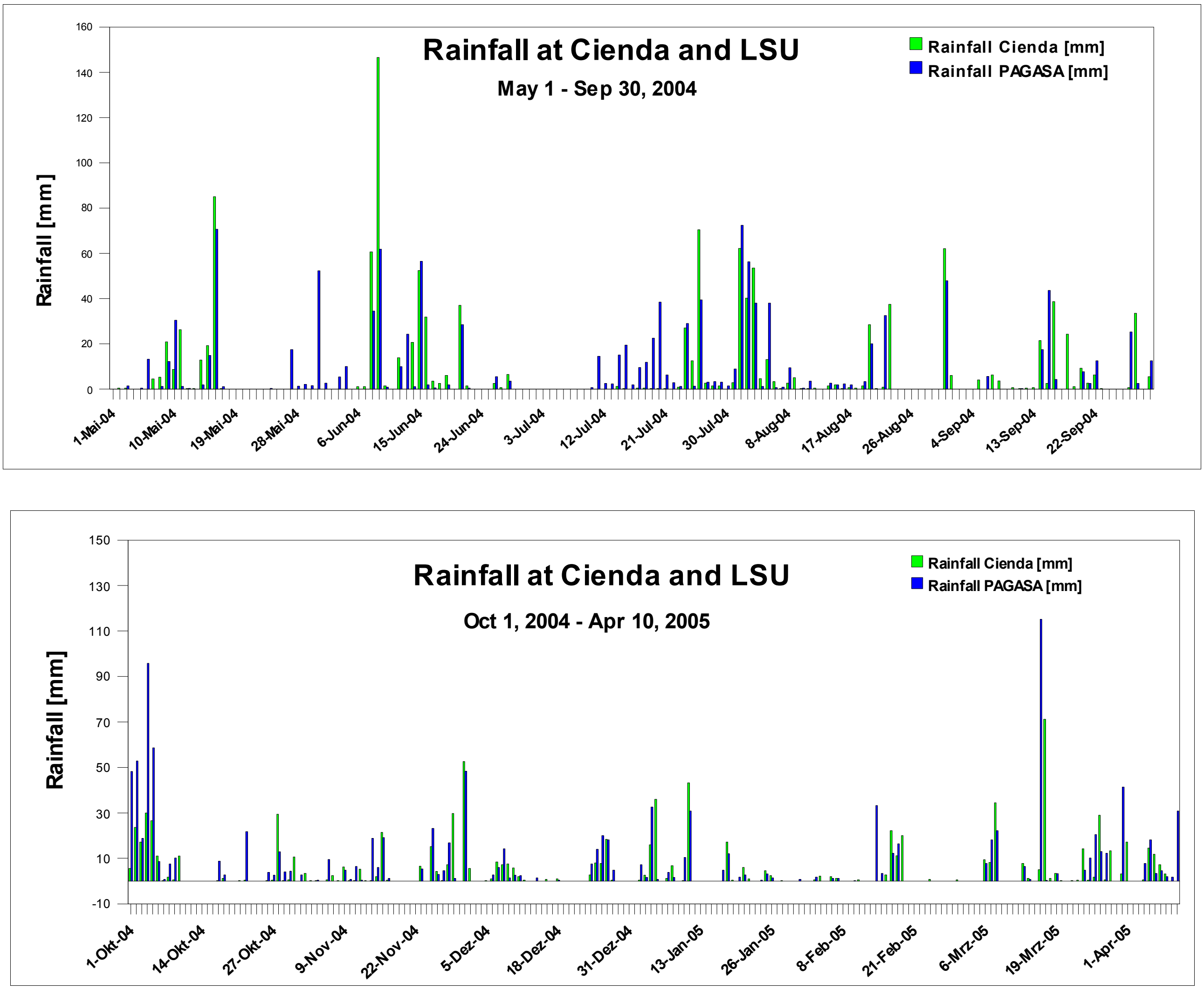

Figure 9: Rainfall at LSU and Cienda sites

For air temperatures, differences typical for continental versus maritime climates could be observed on a small scale: The land inward site Cienda showed higher daily amplitudes for minima as well as for maxima compared to coastal LSU in 2004 - 5 (fig.10). Coincidence of the lowest maxima values at both sites can be taken as a quality control of measurements. Many days with low maxima at Cienda could be explained as clouds stopped by the mountains. Annual means for LSU, however, exceeded the ones at Cienda clearly with respect to maxima and slightly for minima.

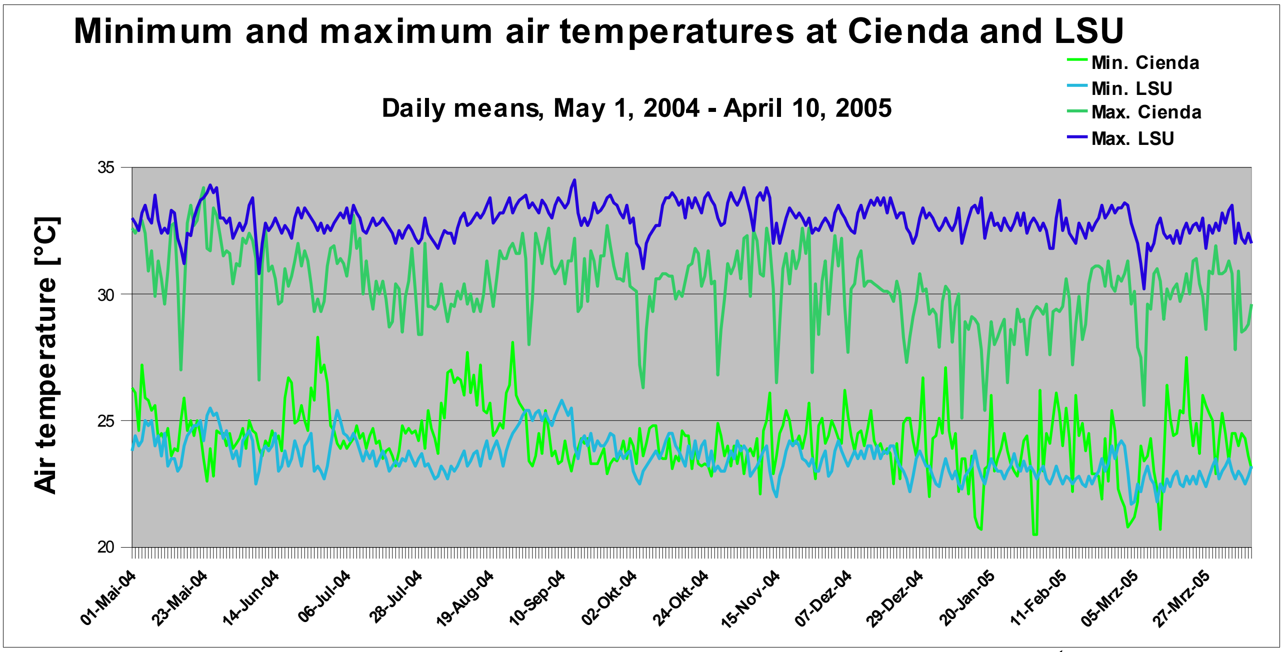

Figure 10: Minimum and maximum air temperatures in Cienda and LSU from May 1st, 2004 until April 10th, 2005. Note the stretched scale, which may overemphasise some trends

Soil climate has been classified as isohyperthermic, i.e. above 22°C throughout the year with amplitude of less than 6°C in 50cm depth (Asio 1996).

1.1.4 Natural vegetation

The Visayas are part of the paleotropic Malesian Floristic Region, Philippinean Province. The latter includes the entire Philippine archipelago to the exception of Palawan and the Calamian Islands. After the most recent glacial period and the subsequent rise of the sea level the Philippinean Province was separated from Borneo, Sulawesi and New Guinea (Rangin et al. 1989, as cited by Langenberger 2003), to which it had been linked before. Australian and mainland Asian species, which occur naturally in the Philippines, indicate that there were land bridges between today's Mindanao and the Australian Region and also between Luzon and Taiwan as well as the Asian continent. Still, the Philippines host many endemic species, which is characteristic for islands.

DENR/UNEP (1997) report, that 5% of the World's flora, more than 13500 species, and 22.5% of the Malesian vascular flora grow in Philippine forests. Davis et al. (1995 as cited by Langenberger 2003) found that 39% out of 8900 vascular plants were endemic, and Langenberger (2003) identified 52% endemic tree species in his survey conducted on the slopes of Mt. Pangasugan, Leyte.

There have been various tree species inventories in the Philippines, starting from the classical study by Whitford (1911), who established the classification of Philippine forest types, which is still used today. According to Whitford, ten main forest types can be distinguished in the Philippines. All of these except the Pine Type Forest exist in Leyte and are described in more detail as an idealised toposequence from shore to summit with special reference to Mt. Pangasugan (table 2).

Table 2: Forest types of Leyte after WHITFORD (1911). Explanations on habitats by Langenberger (2003 and pers. comm.)

1	Mangrove type forests
2	Beach type, dominated by *Terminalia spp.* and *Calophyllum spp.*
3	Lauan-Hagakhak type prevails from sea level up to 150m asl and in higher elevations along riverbeds. Temporary waterlogging and even flooding is tolerated. Species are adapted to a short or no dry season and are almost evergreen. Apart from *Shorea contorta* and *Dipterocarpus validus, Toona kalantas*, *Dracontomelon dao*, *D. edule*, *Terminalia microcarpa* and *T. nitens* are typical trees of Lauan-Hagakhak forests. Palms, lianas and smaller trees are typical understorey species.
4	Yakal-Lauan type forests grow at sea level in climates without or with short dry seasons and are slightly deciduous. On the slopes of Mt. Pangasugan this type was found on steep and/or dry sites as well as on old landslides together with long-lived pioneer species.
5	Molave type: The dominant and eponymous species is Molave, *Vitex parviflora*. This forest type is bound to lower elevations from 0-150m asl, occurs in climates with no to distinct dry season, and is deciduous. Often it is restricted to dry sites by competing Dipterocarp forests.
6	Lauan type: Different Dipterocarp species occur jointly and dominate this forest type. They form a homogeneous evergreen canopy of up to 50m height. Elevation range is from 0-400m asl, with short or no dry season. In Baybay this type can still be found on moderately steep sites with comparatively deep rooting space around 400m asl. Typical places for Lauan type forests are deeply weathered peneplains like the Cienda demo farm (s. 3.1.4).
7	Lauan-Apitong type forest is found between 0 and 400m asl, but in areas with a pronounced dry season. As a consequence species are deciduous.
8	Tangile-Oak type forest, named after *Shorea polysperma* (Tangile), can be found mainly on ridges of Mt. Pangasugan from 400-900m asl. Typical species like *Tristania decorticata*, *Hopea acuminata* or *Cinnamonum mercadoi* are adapted to a short or no dry season and evergreen.
9	Mossy type forests are restricted to higher elevations (above 900m asl). Trees are evergreen and often stunted in growth.

According to WHITFORD (1911), numbers 3 to 7 represent the Dipterocarp forest dominated by approx. 75% dipterocarp trees. Other important families growing below the Dipterocarpaceae canopy are Ebenaceae as well as Rubiaceae, Euphorbiaceae and Myrsinaceae in the understorey.

Although the craggy and fragmented terrain on Mt. Pangasugan's slopes makes it difficult to directly apply WHITFORD's scheme, some of the main categories are supposed to dominate the area west of Mt. Pangasugan. These are Beach Forest and Lauan-Hagakhak in lower elevations and Lauan Type on plateaus. Above 450m (lower montane forests), species belonging to Mossy Forest can be found.

Apart from elevations commonly used for categorisation, LANGENBERGER (2003) found that to an even larger extent species composition is determined by relief position. In a vertical zonation of dipterocarp forests, he found the highest species diversity in the undergrowth, a somewhat lower influence on plant biodiversity was attributed to relief position.

Another important impact factor on plant biodiversity is, according to CONNELL (1978), non-equilibrium, which is typical along Leyte central cordillera with its relatively young soils and frequent landslides.
An important aspect with regard to the establishment of plantations and for reforestation is availability of seeds. Mature mother trees have to be observed regularly and visited for seed harvest. As these trees are scarce and often situated in remote areas, age of first flowering and fruiting has been monitored by some authors to assess the feasibility of seed nursery installation.
Estimating the life cycle of dipterocarp trees between 300 and 1400 years (and maturity for extraction about 70-140 years), NG (1966) notes the first flowering age of 50 dipterocarp species planted in an arboretum in Kepong, Malaysia, between the 20th and 30th year, mentioning also high variability between individuals of the same species. FOXWORTHY (1932, as cited by NG) observed first flowers for some of the same species at 6-20 years, which corresponds with findings of LANGENBERGER (2005) and own observations.

1.1.5 Population, culture and economy[12]

1.1.5.1 Population and housing

Among the 76.5mn inhabitants of the Republic of the Philippines in 2000 (according to the census of 2000; in 2004 there were 83.75mn), the Eastern Visayan or Region VIII holds a share of 4.72% (see table 3). Out of these, 54% lived on Leyte island in 2000. In relationship to land area, 2.74% of the Philippine population reside on 2.85% of the national territory, namely Leyte island, including provinces Leyte, Southern Leyte (split from Leyte province in 1959) and Biliran (split off 1992). The ratio of land area / population almost doubles, when the less densely populated Samar provinces, also part of Region VIII, are included in the calculations.

Table 3: ***Population of Leyte Island in (calculated after NATIONAL STATISTICS OFFICE 2000)***

	Population	Population [%]	Area km^2	Area [%]
Philippines	76.498.700	100.00	300.000	100.00
Eastern Visayas	3.610.355	4.72	21.432	7.14
Leyte	1.592.336	2.08	6.268	2.09
Southern Leyte	360.160	0.47	1.735	0.58
Biliran	140.274	0.18	555	0.19

The Philippines are often referred to as the country with the highest population growth in entire Asia. This has been linked to the strong influence of the Roman Catholic church on the causes[13] and to the rapid decline of natural resources (which were once the base for one of the richest East Asian nations) and increase of poverty (DARGANTES & KOCH 1994) on the effects side. Still, KUMMER & TURNER (1994) found, that a statistical correlation of deforestation could be established rather to legal and infrastructural than population factors. Compared to nation-wide 2.36%, population growth rate in Leyte province was only 1.13% (during the reference period 1995-2000), having dropped from 1.89% during the previous quintennial.
In Leyte province, about 21% of the population lived in the two major cities of Tacloban

12 Official data from the National Statistics Office, census 2000, or own calculations based on these figures, if not stated otherwise.
13 E.g. in 2005 the catholic church campaigned massively against governmental family planning initiatives.

(Province Capital) and Ormoc and another 6% in Baybay, Leyte's biggest village. The remaining residential areas consist of 40 municipalities, which are subdivided into Barangays of usually 1.000 to 2.000 inhabitants.
Household size in Leyte province in 2000 was 4.92 persons, who shared less than $10m^2$ floor area in 25% and less than $20m^2$ in (cumulative) 51% of the households. For the Eastern Visayas, 51% of households were supplied with drinking water from a community grid, 18% out of these having an individual faucet. 48% used electricity as energy for lighting (others kerosene, liquefied gas), 65% of households had radio and 28% television.

1.1.5.2 Culture and human development

In the 2000 census interviews, 40% of Leyte's inhabitants categorised themselves as Bisayan, 38% as Waray, third most important ethnic group was Cebuanos with 20%. Correspondingly, main native dialects are Bisayan, Waray-Waray in the NE of the island and Cebuano; the official Philippino dialect Tagalog is understood in Leyte; a minority speak Kankanai. English has become official teaching language for colleges and universities and is widely spoken by the younger generation and professionals.
Education at elementary level had been achieved by 52% of persons older than 5 years, of secondary level by 23%. In a Human Development Index survey carried out by the National Statistical Coordination Board in 2000, Leyte ranks 49th and Southern Leyte 31st among the 77 Philippine provinces. Both improved 7 and 6 ranks, respectively, since the last survey in 1997. HDI is the product of weighed factors describing life expectancy, education (enrolment and functional literacy) and real per capita income.
Dominating religion as in most regions of the Philippines is catholicism (93%), being competed by an increasing number of other christian groups.

1.1.5.3 Economy and income generation

Gross Regional Domestic Product of Region VIII grew 6.9% in 2004 as compared to the previous year. Shares of the three main sectors were evenly distributed (see fig.11). The agricultural, fisheries and forestry sector is clearly dominated by its first subsectors which contributed 99.9% of GRDP and since 2000 maintained a relatively stable annual growth around 5%. Forestry sector is slowly recovering after shrinking to 0.6% of its year 2000 size within only three years.
According to the National Statistics Office's Special Review on Agriculture (2004), about 30% of the households in Region VIII (for Leyte 20%) owned agricultural land, the average farm size for Leyte being 1.9ha. Main agricultural product of the Eastern Visayas was rice before tubers / roots / bulbs, corn and sugarcane among the annual crops (in Leyte corn ranked second). Irrigated land amounts to almost 19% of agricultural areas and is mainly used for rice production.
Coconut dominated the permanent crops

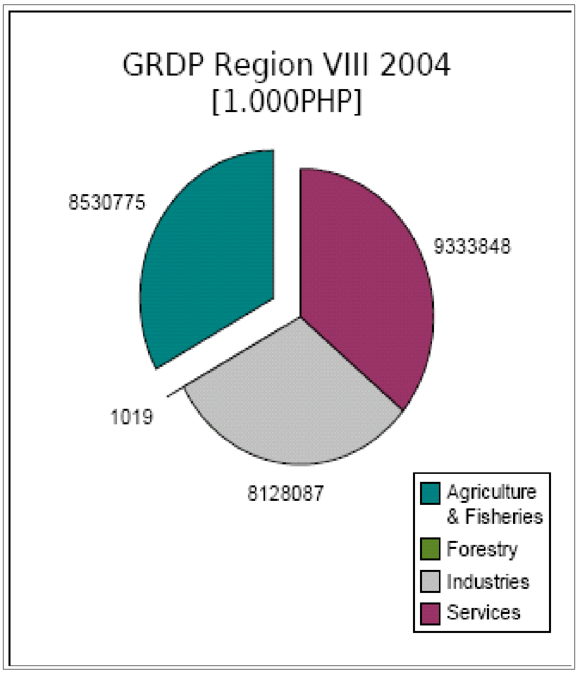

Figure 11: Gross Regional Product Region VIII (source National Statistical Coordination Board)

followed by abaca (mainly from Southern Leyte) and banana (data based on individuals, not hectares).
Livestock production in Region VIII is concentrated in Leyte with approx. 200.000 heads of hog. Other important species are carabao (water buffalo) and chicken, which have doubled in numbers from 1991-2002.
Leyte and to a larger extent Samar are among the poorest Philippine islands, which can be concluded from income-related indices. Real per capita income in 2000 was 13.267PHP for Leyte, less than two thirds of the philippine average (21.104PHP). Where available income is not sufficient to cover the costs of food and basic needs (determined on an average basis), the household would drop below a theoretical poverty line. Although costs of living are lower in the country-side, the situation for rural Leyte became more severe between 1997 and 2000, whereas in urban areas improvements could be observed (see fig. 12).

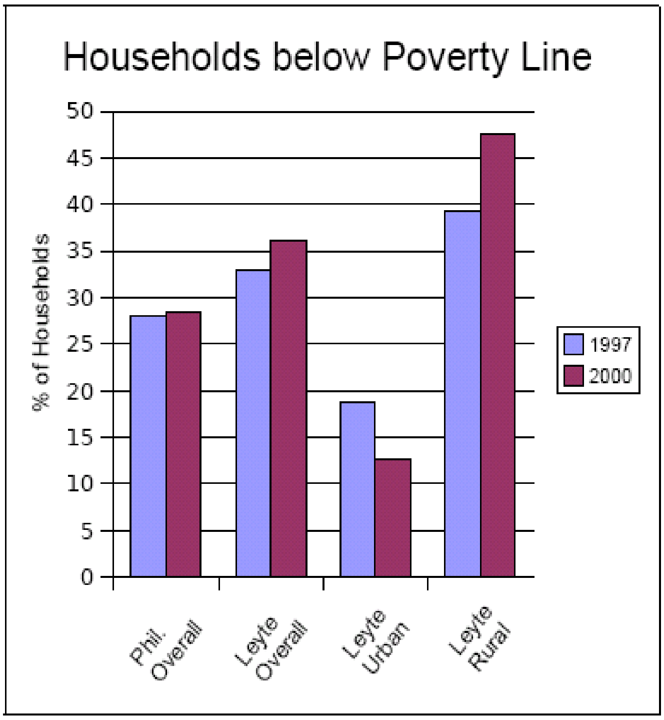

Figure 12: Number of households below poverty line (after National Statistical Coordination Board)

For four barangays in the research area, a sociological survey carried out by Dagoy et al. (1994) showed, that 70% of households were squats and most depended on land areas smaller than one hectare. One of the most urgent shortcomings mentioned in >200 interviews was land tenure (no official titulation) apart from income and job problems. A large proportion of the dwellers were migrants. Asio (1994) mentions violence (World War II and political conflicts during the 1970s to 80s) as a main cause for migration apart from government resettlement programs, that issue stewardship contracts on state-owned land in remote areas. Dargantes & Koch (1994) investigated motives and habits of migrants, who as a consequence of lacking official land title and job opportunities often see forest resources as a source of monetary income. These so-called forest farmers represent the lowest socio-economic class in society. They perceive forests as common goods. Some practice a merely extractive form of income generation, that frequently extends onto private land. Others take a piece of forest land under cultivation with or without informal consent of the present owner or community. Often these informal claims are recognised among villagers and remain valid over generations (pers. comm. of a forest farmer from Guadalupe, Baybay). This kind of customary law can be based on the fact that a person was the first to clear an area of natural forest and cemented by successive planting of coconut trees. Even officials of social forestry and land reform projects are reported to consider these factors once the area is declared *Alienable & Disposable* (Dargantes & Koch 1994).

1.1.6 Land use, tenure and reforestation

Originally the Philippines were mostly covered by forests, agriculture being practised only along the coasts. Among the plant species of most commercial interest were the hardwood timbers of the Dipterocarpaceae family, which are known under trade names such as Red and White Meranti, Merawan or Balau (SOERIANEGARA ET AL. 1993) or Philippine Mahogany, among others. The economic value of these timbers led to drastic deforestation, which started during colonial times under the Spaniards. LASCO ET AL. (2001) estimated, that until 1521, still 27mn ha (90% of the area) of the Philippines were covered by primary forests. Under the Spanish regime, deforestation at a larger scale began. When the Philippines were 'handed over' to the USA in 1898, still 70% of the land area were primary forest (KUMMER 1992). Most parts of the Philippines suffered severe deforestation especially during the second half of the 20th century. Due to the high profitability of Dipterocarp forests (high density of premium timber per land area), and rising demand for Southeast Asian timber in Europe, the USA and Japan, more than half of the Philippine rainforest were logged over between 1945 and 1987 (KUMMER & TURNER 1994). PULHIN ET AL. (in CHOKKALINGAM ET AL. 2006) compiled historical data from different sources, demonstrating, that forest area has steadily decreased from 17.2 to 7.2 mn ha (equivalent to 57 and 24% of the country's area) between 1934 and 2003. Deforestation rates reached an all-time high of 300,000ha a^{-1} from 1977-1980 (GUIANG in DURST ET AL. 2001). According to the DENR Forest Management Bureau (2001; as cited in LASCO ET AL. 2004) less than 1mn ha of old growth forests exist to date and the Philippines have become a net importer of wood (DURST ET AL. 2001) .
Some Visayan islands like Negros and Cebu have been completely clear-cut. For Leyte, 60% of the original forest had been clear-cut by the end of World War II; by the 1990s despite a nationwide logging ban implemented stepwise starting in the 1980s[14], only 10% of primary rainforest were left (ASIO 1996, quoting BARRERA 1954 and DEPT. OF AGRICULTURE 1992). The declaration of logging bans without providing the necessary means for control had shifted most of logging operations into illegality and exacerbated the situation (GUIANG in DURST ET AL. 2001). Remaining patches of primary forest are mainly located in the steep and inaccessible parts along the Cordillera Central. During the 1990s the average annual deforestation rate amounted to 89,000ha or 1.4% of the forested areas[15].
NAMRIA (2003, based on an SSC-SPOT survey 1987-88) statistics tell that forested areas comprise 37% in Leyte and 49% in Southern Leyte. It is noteworthy, however, that *forest* from this point of view is a tenurial rather than biological category (s. below) and out of the 301,290ha of forested land in Leyte, only 7,570ha are old growth and 56,677ha are residual forests, the remaining majority being reproduction and brush area. Also according to NAMRIA forest cover statistics, less than 5% of the so-called forest area represents closed vegetation. DARGANTES & KOCH (1994) give similar figures: Out of the 309,000ha officially proclaimed as forest area (per definition all land >18% slope), 170,000ha underlie different land-uses, and only 93,000ha or <12% of Leyte's land area are still under forest. A more recent survey (FMB, Dec 31st, 2003[16]) lists 65,977ha of forests for Leyte province, 57,332ha of open and 3,962ha of closed forests.
After conversion of part of Leyte's original forest vegetation to secondary forest due to logging operations, large parts of the upland areas were colonised by farmers, who often

14 For Leyte in 1982 by MNR Administrative Order No. 31. LASCO & PULHIN (2003) state: *The other forest types have been protected since 1992 under the National Integrated Protected Area System (NIPAS). However, most of these areas are protected only on paper and remain open access.*
15 FAO 2000: www.fao.org/forestry/fo/fra/index.jsp
16 Download from http://forestry.denr.gov.ph/landuse8.htm Sep 25th, 2006. Plantation forests are not included.

followed the logging roads. According to FDC-UPLB and FAO (as cited by Durst et al. 2001), only 10% of forest losses originated directly from logging operations, while slash-and-burn in logged-over areas (60%) and agricultural expansion (30%) accounting for the majority. Generally, the secondary forest was then cleared and planted to annual crops (traditional kaingin slash-and-burn system) or coconut. Besides the dominating coconut areas, nowadays scrublands and grassland cover large parts of the land. According to NAMRIA, 2003, non-forested areas are distributed as follows: 176,198ha are under coconut, 93,707 under to grassland and 77,024 under agricultural use (fig.13).

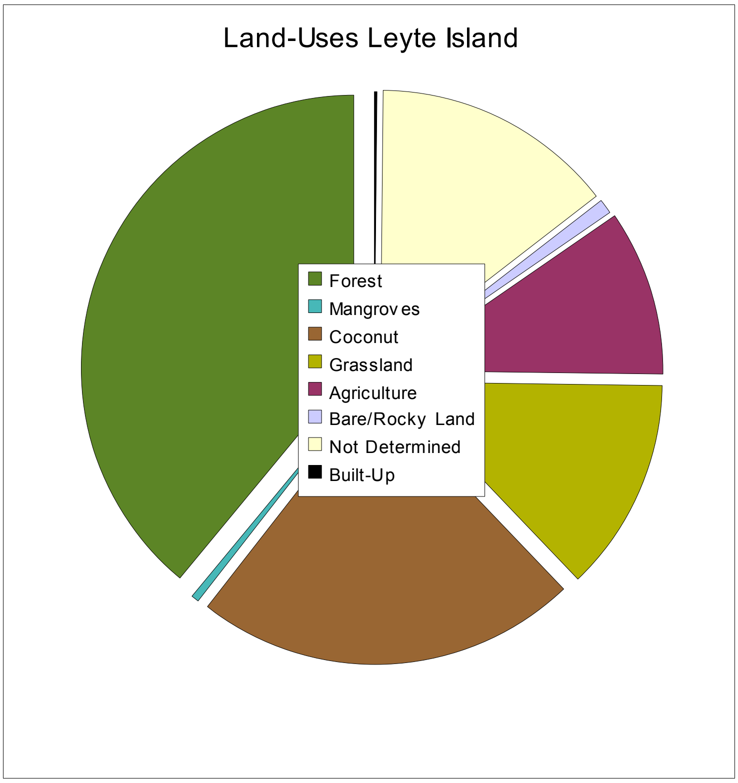

Figure 13: Shares of different land-uses in Leyte (compiled after NAMRIA 2003)

Productive <u>lowland areas</u> along the densely populated coast are generally planted to paddy rice. Around Ormoc commercial use as pasture or sugarcane plantations is common; these lands are relatively scarce (< 1ha/family) or unevenly distributed, so that most small farmers additionally, some exclusively, depend on remote upland areas' products for home consumption or income generation (Dagoy et al. 1994). Among the different forms of <u>upland cultivation</u> the following are most common:

- Perennial systems like coconut in combination with pasture or secondary forest with abaca; these seem to be linked to titled land;
- traditional slash-and-burn practice (*kaingin*) followed by planting of annuals like tubers; such lands are mainly (state-owned) forest areas under customary law;
- typical products harvested by *forest farmers* are abaca, banana, tubers, pineapple and coconut. Hunting and extraction of NTFP like honey or rattan may also contribute to forest farmers' income.

For Leyte island land uses are shown in fig. 14, a GIS-map based on SPOT satellite imagery. A typical zonation of land areas in a village in Baybay district is shown in fig. 15-16).

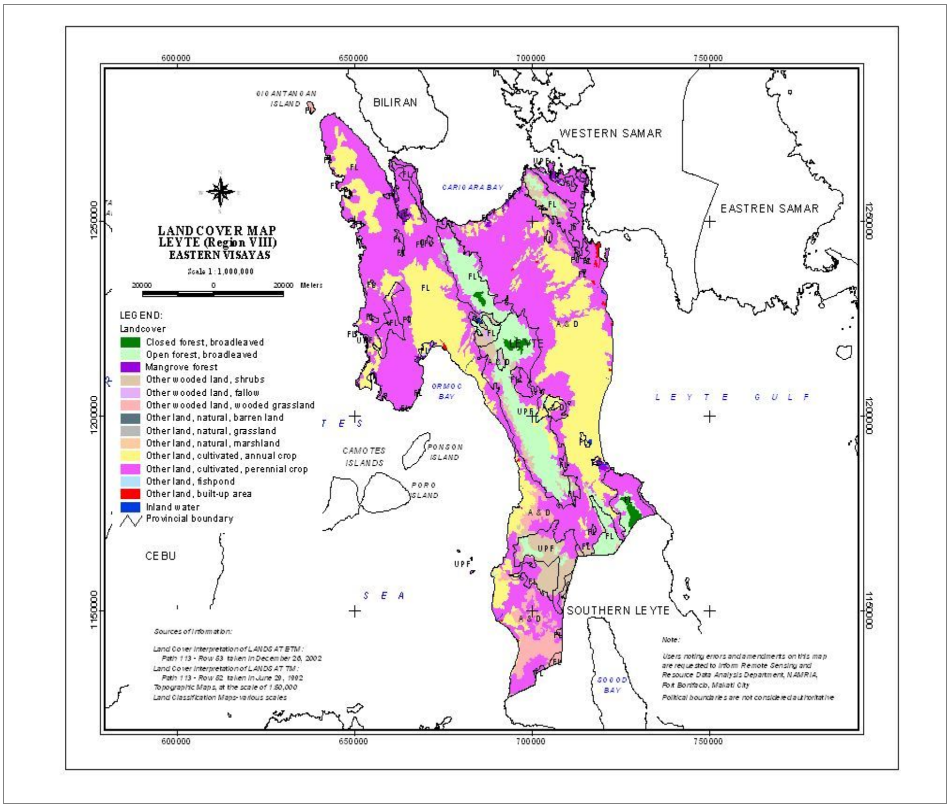

Figure 14: Land cover map issued by FMB-DENR. Dark green signatures indicate natural old growth forest, light green secondary forests, pink coconut and bush fallow, yellow rice or sugarcane

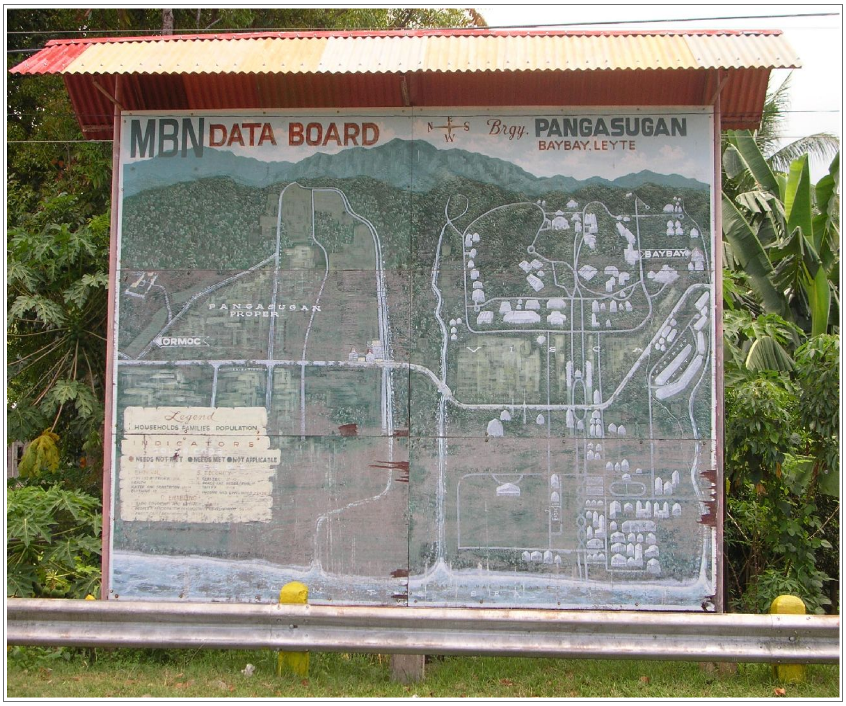

Figure 15: Barangay data board of Pangasugan showing typical zonation of different land uses. Right half LSU, left half, from bottom to top: Seashore, rice fields and village area, coconut area, forested mountain range

Figure 16: Typical land use in Baybay: Rice paddies on levelled lands, followed by old coconut plantations, secondary forest, natural landslides on the steep slopes and old growth forest around the summit of Mt. Pangasugan

Different kinds of land tenurial status coexist, from official A&D (alienable and disposable) and titled lands to squats or the traditional hereditary right to land use conceded by the community to the person who first cleared the forest. These customary rights coexist with state law, which establishes, that all areas >18% slope are by definition forest lands and as such excluded from agricultural use; many of the traditional kaingin areas are in fact found on slopes of >100% inclination. Durst et al. (2001) observe, that *more than 5 mn ha of public forestlands in the timberland category are not covered by any form of tenure, and are considered 'open-access' areas*. Even the official legislation reflects the conflict between agricultural use and protected areas, as the designation of land to either land use was frequently reversed depending on the change of political authorities (Dargantes & Koch 1994).

The Philippines were one of the first Asian countries to initiate reforestation programmes Chokkalingam et al. (2006) distinguish three periods of reforestation efforts, from 1910 until the US colonial regime, from 1946 until the mid-1970s (which coincides with the highest deforestation rates) as government initiatives and until today as multi-sectoral approaches. It is remarkable, that during the first and second phase, the Philippine authorities used mostly indigenous species for reforestation. Phase 3 extended activities to the private sector and social forestry projects carried out by NGO; international funds were also involved to a high degree. The background of these efforts was an imminent timber shortage and consequently 80% of the planted trees were fast-growing exotic trees (mainly *Swietenia macrophylla*, *Acacia mangium*, *A. auriculiformis*, *Eucalyptus spp.* and *Gmelina arborea*).

On the other hand, government institutions actively contributed to land conversion through settlement projects. Planting of coconut was frequently considered by authorities an argument pro legalisation of squatted areas (Dargantes 1994). Kummer & Turner (1994) as

well as Dargantes (1994) see government colonisation projects in conjunction with institutional corruption and export-oriented policies as a main driving force of deforestation (see also Guiang in Durst et al. 2001). Recently, the classical colonisation projects including reforestation with fast-growing tree species (s. 1.2.1) have been complemented with CBFM (community-based forestry management) and similar approaches. Such projects are based on a zoning into protected areas, buffer zones with limited, controlled, traditional and multiple use, the latter being not restricted. Despite the participative background of these programmes, it remains unclear, how farmers' communities with their limited resources can control the appropriate use of these areas. In addition, progressive legal initiatives are often not executed due to lack of personnel (Groetschel et al. 2001) or political intrigues.
FAO classifies almost 70% of the Philippine terrain as too steep, eroded or shallow for agriculture (Land Capability Classes M, N, Y. FAO Gateway for Water and Land Information, online source). Obviously, transformation of these steep forest sites into agricultural use lead to serious erosion problems even for relatively diversified smallholder farms (e.g. abaca, tubers, banana) under canopy. For wide-spaced extensive coconut plantations, degradation would be even more severe. Loss of forest cover in combination with excessive rainfall causes erosion with subsequent loss of soil fertility and stability, declining yields, danger of catastrophic man-made landslides and siltation of rivers and marine ecosystems.

1.2 Agroforestry systems

In this study agroforestry systems are understood as trees grown simultaneously with annual or perennial crops in the same parcel[17].
Among the numerous agroforestry systems developed worldwide through centuries, some common aspects are, that different species benefit or at least complement each other or that farmers expect higher outcomes, in the form of yields or revenues, environmental services or risk and labour minimisation.
Some assets attributed to such systems are:

- Soil protection through a multi-storey canopy, which reduces erosivity of rainfall (Wischmeier & Smith 1978)
- Reduction of microclimatic extremes under the closed canopy and maintained soil moisture favour growing conditions for shade-tolerant understorey and late-successional plants. Soil microbial biomass and biological activity can also be enhanced under such conditions (Yan et al. 2003; Mao et al. 1992; Martius et al. 2004).
- Effective resource use is facilitated through multi-storey canopies; belowground, the safety net and nutrient pump function of deep-rooting trees can prevent mobile ions from being leached (Schroth et al. 2001); nutrient cycles are kept tight. Minerals are transferred from deeper soil layers via leaf litter to the topsoil, where shallow-rooting plants can make use of them (Cannell et al. 1996). Diversity of trees can foster diversity of mycorrhizae and increase strategies of nutrient utilisation; overall productivity can be increased through better resource use (He 2005).
- Diversification in plant species as a strategy to increase structural and organismic diversity can increase resilience of the system. It is expected, that self-regulation can to some extent control pest populations (Schroth et al. 2000).
- Economically, peaks of labour demand can be flattened as planting, management and harvesting activities will be more spread with an increasing number of crops grown. The

17 Some authors include sequential systems; those are not considered here.

monetary risk when loosing crops or of dropping producer prices can be reduced by diversification of marketable products. (ANDERSON & DOMSCH 1985; PADOCH ET AL. 1985)

- Diversification of products for home consumption can improve nutrition and health of farmer families.
- Recently the potential of agroforestry for CO_2 sequestration has been assessed (MONTAGNINI & NAIR 2004). Under the principle of additionality[18], calculations can be made only in comparison to a referential land-use system (SCHROEDER 1994). Although well-managed pasture has been reported to contribute comparable amounts of organic (V. NOORDWIJK ET AL. 1997) and microbial (IZQUIERDO ET AL. 2003) carbon to the soil, aboveground biomass C accumulation will certainly be higher in agroforestry systems.

Differences in agroforestry systems exist with respect to species richness and resemblance of natural ecosystems (ASHTON & DUCEY 2000). Traditional systems were often of minimal impact and close to nature. Examples are fruit trees deliberately planted along gathering and hunting trails in the forest (HECHT & POSEY 1989); enrichment planting in official forestry programmes might be adoptions of these ancient experiences. Hundreds of years ago rainforest dwellers made use of detailed knowledge of soils, species and natural succession (SALICK 1989), selected promising varieties of fruit trees and integrated them together with annual crops into natural ecosystems under consideration of small-scale soil characteristics (BALÉE 1989).

A more technological approach was chosen from the 1970s onwards, when alley- and hedgerow-cropping, silvo-pastoral systems and timber plantations of fast-growing species were introduced. Especially the latter were criticised to impoverish soils (in the case of *Eucalyptus* plantations in South America) or erode the genetic diversity of native species through introduction of high-yielding varieties (RAO, SINGH & DAY 2000). On the other hand some authors highlight, that diversification of species should not be overemphasised as long as a set of ecological functions is maintained (RUSSELL 2002; LANGI ET AL. in GEROLD ET AL. 2004).

During the last decades the traditional techniques and knowledge were rediscovered and documented (BRECKLING & BIRKENMEIER 2000) and new systems were developed and implemented (ASSOCIACIÓN DE AGRICULTURA ECOLÓGICA 1998; MILZ 2001). Many of these were based on ancient experiences of indigenous tribes. Special attention was given to natural succession (EWEL 1999; MONGELI 1999), functional groups of plants (*guilds*, MOLLISON 1988) and imitation of structural and species diversity of natural forests (COICAP 1999).

1.2.1 Rainforestation

The Closed Canopy & High Diversity Forest Farming System was initiated by an international organisation in a development, not a research context. Consequently the term *rainforestation* was coined as a marketing instrument rather than a strict scientific definition. The theoretical framework of rainforestation is based on the assumption, that a system imitating the natural climax vegetation (here: dipterocarp forest) in physical structure and species composition should be the most resilient possible land-use. Basic principles are the 3-storey structure and focus on native species as well as the four guilds of lumber, fruit trees, climbers and shade-tolerant tuber crops, which are to be planted (MARGRAF & MILAN 1996). On the other hand promotion of a standardised planting pattern has been deliberately omitted; concerning planting distances and choice of species, the scheme may be modified with respect to farmers' preferences, site characteristics and availability of seedlings. Departing from the era of fast-growing 'miracle trees', *Gmelina spp.*, *Acacia mangium*, *Swietenia macrophylla*, *Eucalyptus spp.* and other exotic species

18 A prerequisite for CDM projects to be accepted.

were initially part of the rainforestation pattern. These were complemented with *Citrus spp*. for more rapid income generation (Posas, personal communication). By the time, focus shifted more and more towards native – especially high-value Dipterocarpaceae – species and resulted in a total ban of exotic trees (Margraf & Milan 1996) as these had been discovered to be less resistant to extreme climatic events (Kolb 2003) and more susceptible to numerous pests and diseases (Chokkalingam et al. 2006). The approach was tested in various planting patterns, from loose random position to high-density straight lines of 2x2 and even 1x2m. One lesson from the early days of rainforestation was to distinguish pioneer and shade-loving trees, the latter ones being planted after the establishment phase of the first (usually in two subsequent years). Yet, even shade-loving timber trees exposed to full sunlight can attain high survival rates (Quimio 1998), as long as proper maintenance is guaranteed. Although starting from a forester's perspective, other guilds as fruit trees, climbers and shade tolerant tuber crops like *Dioscorea sp.* or *Colocasia sp.* were also included.

From the Philippines, a variety of traditional agroforestry systems have been reported. An early scientific description of such systems was the Hanunóo example by Conklin (1957), a system of swidden agriculture, which integrates *Cocos* and *Areca* palms, cocoa, malay apple, jackfruit and mango trees, bamboo and abaca after a first phase of annuals and banana. The Naalad system in Cebu, based on bundles of Leucaena branches placed in the field, has helped people to reduce fallowing periods, although slow depletion of the soil cannot be totally avoided (Lasco & Suson, unpublished). In Banaue, a more than 200 year-old farming system based on rice terraces includes forest patches of 0,05 – 5ha in size (Lasco unpublished). *Cocos* palm was intercropped since the 1930s with annual crops and banana and later on with fruit trees, *Leucaena sp*. and introduced timber species like *Swietenia sp.* and *Gmelina sp*. (Bullecer & Stark 2004). The official reforestation strategy focussed on the aforementioned as well as *Eucalyptus spp*. and *Acacia mangium*, which were sometimes alternated with fruit trees and adapted to local conditions (Bugayong 2004). However, constraints of this approach such as poor wood quality and retarded growth of the 'miracle trees' after the first years (own interviews with farmers) as well as poor resistance to typhoons (Kolb 2003) are frequently mentioned.

Thus, rainforestation aimed at replacing the kaingin system on former fallows and releasing pressure from primary and still close-to-natural secondary forests. The annual component was intended to guarantee subsistence or even a small income, so that clearing of forest areas would not be necessary anymore. More than ten years after its initiation, rainforestation approach still has not passed the prototype stage and a critical mass has not been reached. Possible reasons for the lacking adoption through farmers are missing ownership (seedlings were given for free and weeding was carried out by project workers in many cases) and low short-term rentability or, as Groetschel et al. (2001) put it, *people cannot address environmental needs due to their short-term economic needs*. Annual crops are demanding in terms of management and rainforestation terrain is usually distant from villages. Another cause for discouragement mentioned by farmers and consultants is the bureaucratic process of tree registration and obtaining a logging permit for planted trees from forestry officials.

Lately, there has been a tendency to integrate abaca (*Musa textilis,* a fibre producer) into the rainforestation design and merge traditional abaca (under secondary forest) and rainforestation systems, thus broadening the approach from a mainly biodiversity-based to a more market-oriented one. Both components are suited for the same tenurial, land-use and ecological zones, namely slopes situated between lowland rice fields and secondary forests, which are mostly under fallow with coconut. Moreover, abaca is not a labour-intensive crop until harvest. Carbon sequestration as an additional opportunity to generate income in the short run could be another asset of abaca planting due to rapid biomass build-up and longevity of the fibres, so that carbon once it has been sequestered would not be released quickly.

1.3 Carbon sequestration

Alarming news about increasing frequency of climate extremes and underestimation of global warming can almost every day be read in the press[19]. Facing an increase of atmospheric CO_2 from 280 to 358ppm since the pre-industrial era as well as a general trend of global warming (Houghton et al. 2001; Schneider v. Deimling et al. 2006), concrete initiatives to reduce Greenhouse Gases (GHG) emissions have been started. Since the Kyoto Protocol entered into force in February 2005 and emission accounting is becoming a reality in many countries, binding commitments have to be met by the undersigned parties and the respective emittents of (GHG) in these countries.
A pacific insular country like the Philippines is likely to be most severely hit by increasing temperatures through the consequently rising sea levels and higher rainfall variability of the Asian summer monsoon, although some models extrapolate an under average warming for the area. (Houghton et al. 2001). Even if a small not industrialised country cannot have a large impact on the global GHG balance, climate-related compensation projects could at least mitigate some of its consequences.

1.3.1 Climate change and carbon pools

An increase of concentrations of atmospheric CO_2 due to industrialisation has been predicted as soon as 1895 by S. Arrhenius[20].
At the current state of knowledge, it is still difficult to quantitatively separate and attribute shares of the greenhouse effect to certain anthropogenic drivers like transport or land use change; at least there is now a broad consensus, that the sum of effects is too high for a natural phenomenon (IPCC 2003). Many of the mechanisms[21] caused by elevated atmospheric GHG concentrations are understood, but orders of magnitude, sometimes even directions of change, are still difficult to predict.
The Intergovernmental Panel on Climatic Change (IPCC) listed the factors contributing to climate change and their warming / cooling impact on the atmosphere relative to the pre-industrial era (fig.17).

19 Examples: 1990s were the warmest decade of the millenium and 1998 was the warmest year for the Northern Hemisphere (Houghton et al. 2001). The six warmest summers during history of measurements in Germany occurred in the last 20 years (Deutscher Wetterdienst). Greenland Ice is melting faster than expected (Velicogna & Wahr 2006)

20 *Der Anstieg des CO_2 wird zukünftigen Menschen erlauben, unter einem wärmeren Himmel zu leben*. [In the future, increase of CO_2 will allow man to live under warmer skies.]

21 Like warming, increased plant growth and decomposition of SOM, rise of sea level (expansion and melting), changes in the thermohaline circulation (Atlantic).

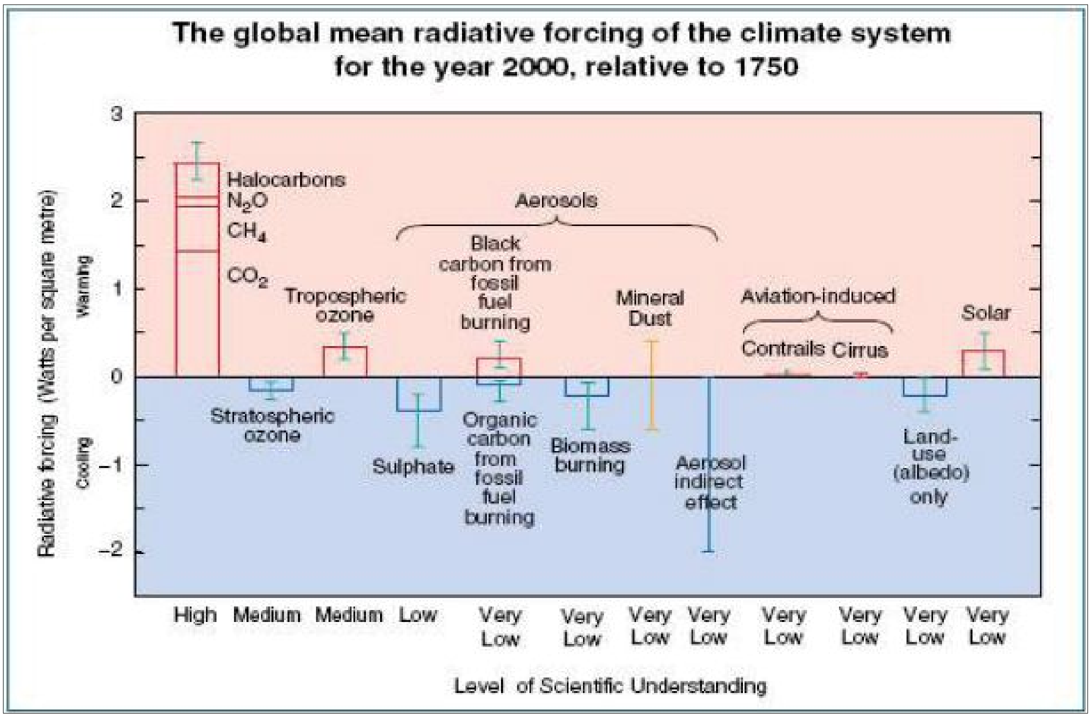

Figure 17: Relative influence of different factors on climate change and scientific understanding of mechanisms. Error bars indicate range given in the compiled studies. Source IPCC (Houghton et al. 2001)

An important share of radiative forcing has been attributed to carbon dioxide, methane and nitrous oxide, which are released from natural as well as anthropogenic processes, and from a range of man-made halogenated hydrocarbons. Carbon dioxide is released from respiration and burning processes, while CH_4 is set free under anaerobic conditions e.g. in soils or rumina and N_2O through denitrification in soils, under anaerobic conditions and depending on N supply and temperatures. Bareth (2000) gives an overview of the relative shares of the main GHG and man-made drivers with respect to climate change (fig.18-20).

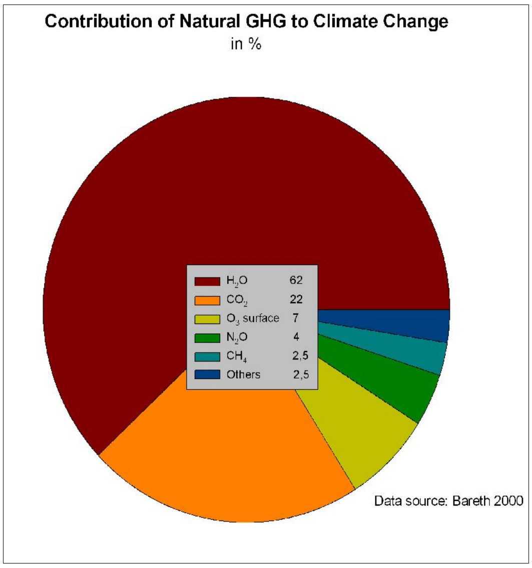

Figure 18: Shares of natural GHG to warming (after data from Bareth 2000)

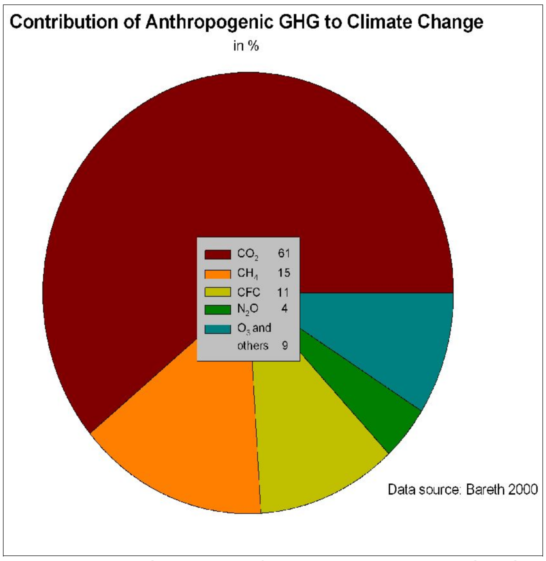

Figure 19: Shares of anthropogenic GHG to warming (after data from Bareth 2000)

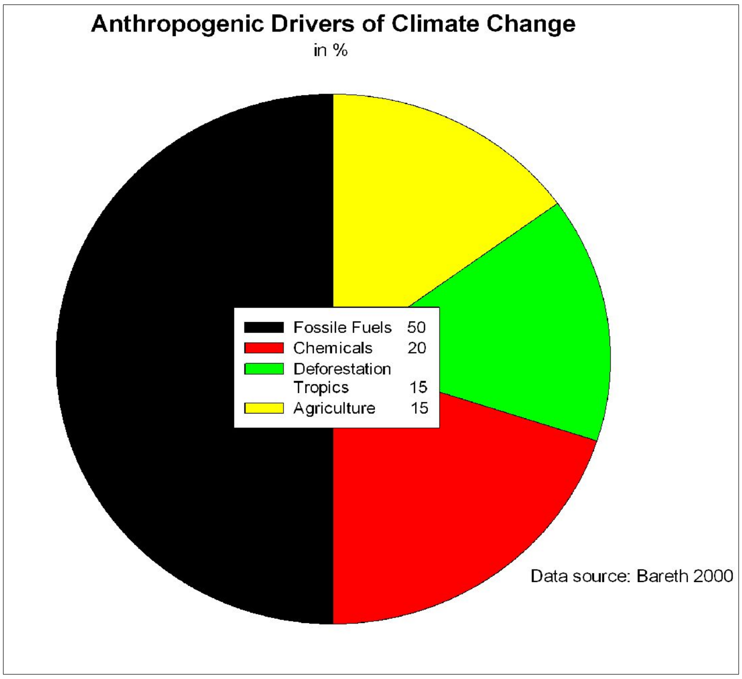

Figure 20: Anthropogenic causes of global warming (after data from Bareth 2000)

As lifetimes and Global Warming Potential (GWP) differ between GHG (table 4), these are usually expressed as CO_2 equivalents for calculations.

Although CO_2 has the lowest GWP of the three gases, it exerts the strongest impact on climate due to its relatively high concentrations in the atmosphere. Among the various pools of CO_2, terrestrial biomass has been a source (Lloyd 1999) of CO_2 or at least neutral (Schimel et al. 2001) for a long time, but is currently a sink[22]. This change has been attributed to higher biomass productivity through CO_2 fertilisation, reducing stomatal conductance and thus enhancing water, light and nitrogen use efficiency, as well as anthropogenic nitrogen depositions (Gifford et al. 2000; Houghton et al. 2001).

Expansion of Northern Hemisphere forests and large-scale land use change in the Tropics like natural regeneration of abandoned lands and fire prevention have also been mentioned as explanations for the increased absorption of CO_2 through terrestrial biomass (Schimel et al. 2001). The feedback of elevated temperatures on decomposition rates and thus release of CO_2 from litter and soils into the atmosphere has been highlighted by Powlson (2005).

Table 4: Lifetime and Global Warming Potential (GWP) of GHG. GWP projected to 20a residence time in the atmosphere

GHG	Lifetime [a]	GWP during 20a
CO_2	5-200	1
CH_4	12	62
N_2O	114	275

An overview of the different carbon pools (based on data presented by Watson at IPCC CoP 6 2001) is given in fig. 21, where red arrows indicate the main anthropogenic CO_2 sources, namely combustion of fossil fuels and tropical deforestation, which lead to an atmospheric build-up of CO_2 in the atmosphere. Oceans are also sinks, but will not be discussed here in detail.

22 Sources release GHG into the atmosphere, while sinks absorb them.

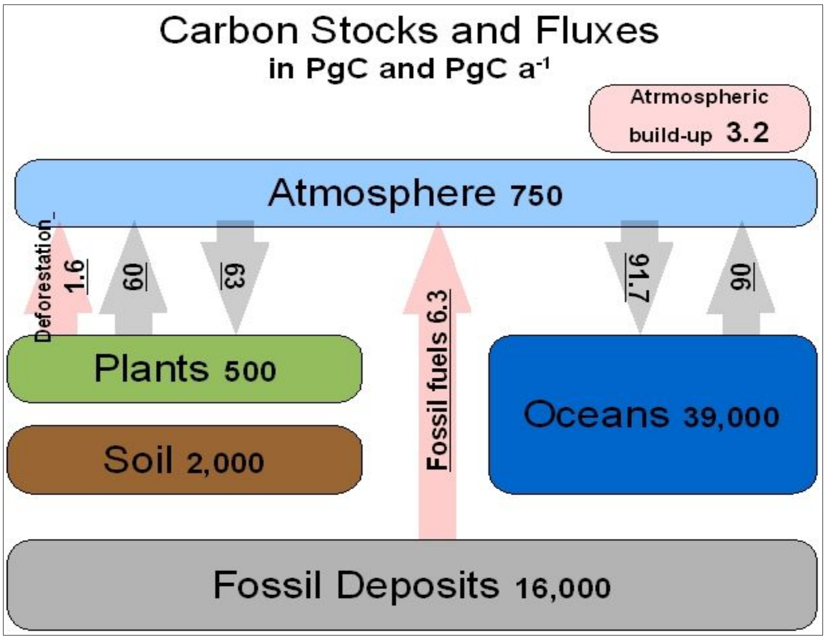

Figure 21: Global carbon pools during the 1990s (data from Watson, presentation at IPCC CoP 6, 2001)

The existence of a residual terrestrial sink of 2-4 PgC a^{-1} (Schimel et al. 2001) has been concluded from the overall carbon balance.
The eminent role of land use change (LUC) in the tropics follows from the aforementioned change of the terrestrial biomass from source to sink. Natural and regenerated forests are seen as key factors to climate stabilisation. Higher productivity of forests through elevated CO_2 levels could lead to increasing carbon storage even at a new productivity equilibrium (Chambers et al. 2001). Of similar importance is the storage of carbon in soils (Schwendenmann 2002), which account for 30% of C in tropical forest ecosystems (Moura-Costa 1996 as cited by Lasco et al. 2004). Especially the passive carbon pool, stabilised by minerals, and also charcoal-C are practically immobilised from the cycle, but transferring carbon from the atmosphere into the passive pool takes long times (Chambers et al. 2001).
Although the importance of carbon in soils has been demonstrated and widely accepted (v. Noordwijk et al. 1997; Guo & Gifford 2002; Murty et al. 2002), carbon budgets of soils are often neglected or assumed to remain stable for accounting purposes (e.g. UNFCCC procedures). Besides soil carbon balances, CH_4 and N_2O pools and fluxes in agroforestry (Verchot et al. 2004), permanence of carbon in pools, saturation of carbon pools, separability and attribution of fluxes (IPCC 2001) are often mentioned as future research needs.

1.3.2 Institutional and legal framework for funding of carbon sequestration through afforestation and reforestation

Most countries worldwide have joined the UN Framework Convention on Climatic Change (UNFCCC). Since February 2005 the Kyoto Protocol as legally binding treaty took effect once more than 55 Parties to the Convention, responsible for more than 55% of Annex I[23] countries' CO_2 emissions in 1990, had acceded.
The Kyoto Protocol obliges all undersigned parties to meet fixed targets reducing their

23 This group includes most industrialised nations, their share of global GHG emissions amounts to 61.6% (UNFCCC 2006).

greenhouse gas (GHG) emissions. The overall objective is to cut global GHG emissions to a level of at least 5% below those of the baseline year 1990 within the commitment period 2008-2012. Developing countries and such in transition to market economy are (partially) exempted, but as a principle the right to pollute is intended to be equally distributed and to be traded. Three instruments were designed to implement polluter-pays-principle, market mechanisms and a theoretical overall control of total GHG emissions: Joint Implementation rewards GHG reduction or removal projects implemented by Annex I parties with Emission Reduction Units. Emission Trading allows participants of Annex I countries with Assigned Amount Units (AAU) to buy CO_2 equivalents in order to meet their emission commitments or to sell them and benefit from reduced GHG emissions. Finally, Clean Development Mechanism (CDM) involves partnership between developed and developing countries in such a way, that participants from the first group can implement GHG reduction or removal projects in developing countries. CDM credits can be acquired and saved before the beginning of the first commitment period in 2008. For this reason initiatives like the Prototype Carbon Fund (initiated as a PPP project by the World Bank with the participation of several government and companies) have already shown interest to realise CDM projects. Potentials of CDM measures in context with rentability have been investigated by Beerbaum (2001).
According to Article 12 of the Kyoto Protocol, purpose of CDM is to assist non-Annex I parties in sustainable development and Annex I countries to meet their emission reduction targets. CDM projects have to generate *real, measurable and long-term benefits related to the mitigation of climate change*; these benefits must be additional to a business as usual-baseline without CDM activities.
The Philippines are a Party to the UNFCCC and have nominated a Designated National Authority (DNA) for CDM issues, the Dept. of Environment and Natural resources (DENR). Thus Philippine projects are eligible for CDM.
Briefly, after receiving a Project Design Document including a socio-economic and environmental impact assessment, Designated Operational Entities (DOE) will validate the plan and, if successful, propose it to the CDM executive board for registration. Project financing can be obtained from any entity interested to buy Certificates of Emission Reduction (CER). During the project cycle, emission reductions are monitored and emission reductions are verified. Finally, the project is certified and CER are issued (UNFCCC CoP9 2003).
Project lifecycles can last 30 or three times 20 years. To assure permanence of the GHG reductions, two kinds of CER are issued: temporary or tCER expire at the end of the commitment period following the one of issuance and long-term or ICER are valid during the entire project lifecycle (UNFCCC CoP9, 2003). The principal activities of GHG reduction are conservation or expansion of carbon stocks and substitution of techniques and processes based on fossil fuels by renewables. Most CDM project activities are currently concentrated in the substitution category, namely in the energy industries (50%, including renewables) and waste management (24%) sectors. Agriculture covers a relatively small share (16%), many projects in this sector are related to biomass power plants and CH_4 reduction. Within the category of expanded sinks, agricultural projects are excluded, only afforestation and reforestation[24] are supported.
Currently, CER of 1bn tCO_2 equivalents are expected to be generated on the basis of existing CDM projects until 2012 (press release UNFCCC secretariat 09/06/06). 306 projects were registered Sep 24, 2006, about half of them in the Asian and Pacific region and one in the Philippines (another one has been submitted for registration[25]). Most of this CO_2 reduction will be accredited in China (45%), Brazil (16%), South Korea (13%) and

24 A&D

India (12%). The most important Annex I countries participating in CDM projects are the Netherlands (68 projects), UK (52), Japan (24), Spain (11) and Canada (11).

1.3.3 Potential of carbon sequestration through agroforestry

There are various agricultural and forestry practices suitable to reduce carbon emissions, like low-impact logging techniques, soil carbon management (reduced tillage, among others), fire prevention or fertilising / liming of forests, which shall not be discussed in depth here. Agroforestry is generally eligible for CDM projects if the respective meets the national requirements of forests (mainly coverage and height, s. below). Respective feasibility and rentability studies have been carried out for several tropical countries (e.g. Ginoga et al. 2005, Shively et al. 2004).

Schroeder (1994) calculated potential stocks of 50MgC ha^{-1} and sequestration rates of 10MgC ha^{-1} a^{-1} during a cycle of 30 years for agroforestry in humid ecosystems. Assuming 160mn ha of land to be available for agroforestry in the tropics, he concludes, that 1.5 to 8 Pg C could be sequestered annually. Dixon (1995) gives even larger areas of 585-1275mn ha worldwide that could be planted to agroforestry. Albrecht & Kandji (2003) estimate that agroforestry systems worldwide could sequester 10-15% of globally emitted CO_2. They give a first approximation of 12-228MgC ha^{-1}[26] sequestration potential for Southeast Asian Agrosilvicultural systems. Finally, IPCC sees a potential of C sequestration by agroforestry systems of almost 0.4PgC a^{-1} (R. Watson, IPCC, presentation during CoP 6 meeting).

Agroforestry has a long history in the Philippines and even been part of the state's land rehabilitation programmes (Chokkalingam et al. 2006), so that there should be sufficient knowledge and experience to establish agroforestry projects under the umbrella of CDM. Potentials of such projects have been evaluated (Lasco et al. 2005b) and proposals are under way. As mentioned, agroforestry projects fall under the category of Afforestation or Reforestation (A/R). However, the definition of *forest*, on which the applicability of A/R projects depends, leaves some flexibility to the host countries: A forest presumes a minimum area of 0.05 to 1ha, at least 10-30% of canopy coverage and 2-5m potential height of the trees[27]. This might lead to difficulties e.g. in the case of existing coconut stands: If the crown cover exceeded the national forest threshold, the stand would be considered a forest and as such could not be reforested anymore. Afforestation and reforestation according to CDM regulations imply, that the respective area has been deforested at least since Dec 31st, 1989. This regulation may pose a problem to countries, where a large share of deforestation occurred since the 1990s, which is not the case for the Philippines.

For A/R in rural areas, small projects would probably best serve development strategies and couple livelihood and environmental goals. So-called small-scale (SSC) projects have been included to CDM and defined as those sequestering less than 8000t CO_2 a^{-1} and involving low-income groups (UNFCCC CoP9 2003). Efforts have been undertaken to simplify procedures for SSC, e.g. through eligibility of bundled projects. The Intergovernmental Panel on Climatic Change (IPCC), a consultative body to the UNFCCC, has elaborated guidelines for validation and monitoring of CDM projects, the so-called Good Practice Guidelines – Land-Use, Land-Use Change and Forestry (GPG-LULUCF). These guidelines give detailed procedures and methodologies to determine carbon pools

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25 Reductions of 96,000t CO_2 equ. are expected annually for a waste water treatment plant, 57,000t CO2 for the NorthWind Bangui Bay Project.

26 Over a lifecycle of 50 years.

27 Detailed prerequisites on eligibility of land for A/R projects can be found in Annex 16 of the CDM – Executive Board's report 22

in ecosystems and rates of change caused by LUC[28]. CDM regulations are based on these guidelines.

To apply for SSC-AR projects, the following criteria are validated: The project boundary must be clearly delimited and a stratification, i.e. mapping of land-use, soil and vegetation, has to be available. Baseline scenarios per stratum have been determined and baseline carbon stocks evaluated. An ex-ante GHG removal calculation per stratum has been performed (only trees are taken into account, soil and undergrowth remain constant) and additionality[29] proven. Reductions for elevated transport, fertiliser, burning, tillage or other CO_2-releasing management (leakage[30]) have been discounted and ex-ante actual net GHG removal calculated. Project implementation, stratification, ex-post GHG removals and leakage will be monitored during the project cycle as described under 1.3.2.

According to Pulhin et al. (in Chokkalingam et al. 2006), the Forest Management Bureau identified a rehabilitation target of 5.5mn ha for the Philippines. Lasco et al. (2004) estimate that there is a potential for CDM-LUCF projects of 2-10mn ha degraded grasslands in the Philippines. On the basis of data published by NAMRIA (2003; s. section 1.1.6) for Leyte island, roughly 270,000ha of non-forested forest land could be theoretically available for CDM projects. Subtracting the area under coconut (a conservative approach in case these would not match A/R requirements), 94,000ha of grasslands would still be potentially available. These areas could additionally be restricted by the national legislation, which generally does not permit agriculture on forest land. On the other hand Agroforestry Farm License Agreements with a validity of 25 years are issued by the DENR-FMB. Legal aspects on this matter (like Certificates of Stewardship for 25a, if the respective land has been cultivated for at least 25a) have been discussed by Bugayong (2004).

At least two reforestation projects in the Philippines are being proposed to the CDM. One of them is the LLDA[31]–Tanay Streambank Rehabilitation Project in Luzon. The LLDA and the municipality of Tanay will sell certificates to the World Bank's BioCarbon Fund. The certificates are planned to originate from streambank rehabilitation, 70ha of reforestation of denuded lands, and 25ha of agroforestry implemented by local farmers. 1400 to 3200t C are expected to be fixed within the project cycle from 2004-14 (Lasco et al. 2005a).

One of the most important uncertainty when assessing prospects of agroforestry for CDM projects is still carbon sequestration itself. As Lasco & Pulhin (2004) state, *there are still limited data on carbon sequestration compared to carbon stocks [...] because carbon stocks can be easily calculated using allometric equations [...], but [...] biomass change and carbon sequestration requires long-term monitoring.*

This study will use data for carbon sequestration acquired from modelling and calibrated with data from field experiments with different timber and fruit tree species on a typical site in Leyte and relate the findings to those of other authors. Opportunities and obstacles shall be assessed from the perspective of AR-SSC applicants to the CDM.

28 e.g. Crop → crop, Grassland → grassland, Crop → Forest and Grassland → Forest

29 Benefits with regard to carbon sequestration, that would not have occurred without the project (baseline scenario).

30 Defined as *decrease or increase in greenhouse gas benefits outside the project's accounting boundary as a result of project activities*, leakage is commonly understood as decrease, i.e. CO_2 offsets into the atmosphere.

31 Laguna Lake Development Authority

2 Sites, material and methods

2.1 Approach

Variability was a key challenge to this study: Apart from relief and soil variability on a small scale, the existing rainforestation plots generally were highly diversified not only in tree species, but also in planting distances and schemes, plot size and management. For this reason, two stages of plots were monitored to describe growth and carbon sequestration potential of rainforestation systems on the one hand and effects of the trees on soils on the other.
Firstly, a 1ha rainforestation plot with a regular planting design was established in 2004 to document the departure point of the system, also as a baseline for future studies. This model plot focused on early yielding species and served to monitor growth and mortality during the first years, which are critical for farmers' motivation, weeding costs and survival of plants. Heterogeneity of the plot with respect to canopy closure and soil was assessed during the first field phase to explain spatial differences in plant performance. Biomass data were later used to validate modelling results.
Secondly, in 2005 soil from different rainforestation plots planted 1992-1996 was sampled as paired plot comparisons each with an adjacent reference area under traditional coconut-bush fallow or coconut-grassland use. For two sites, reforestation with fast growing exotic *Gmelina arborea* was available as a third land-use alternative representing the official reforestation strategy.
The paired-plot approach was chosen in order to detect possible effects of rainforestation systems on soils. Aside from a general characterisation and classification of soils (FAO), parameters were selected that respond to land-use changes within a short- to mid-term period. Besides SOM-related parameters, analyses reflecting microbial activity and litter dynamics were of most interest.
Third, a modelling approach was chosen to extrapolate future biomass growth and carbon sequestration potential from the new plots and also to compare C-sequestration under traditional fallow, *Gmelina* and native trees. For tree parametrisation, which requires mature trees, measurements were taken on individuals from the >10 year-old rainforestation sites, forest sites and well established orchards. For validation an inventory conducted by Kolb (2003) in 2002 was used as a reference to modelling predictions. For abaca parametrisation, Kellman's (1970) allometric equation and v. Noordwijk et al. (2002) gave some trends, yet destructive measurements were carried out on the plots established in 2004.

2.2 Site selection for paired plots

Sites for chronosequence comparisons were selected out of the 28 existing Rainforestation Farms in Leyte, about half of which fitted the minimum criteria of an area ≥0.25ha, *successful* in a broad sense (i.e. not burnt, cleared or abandoned) and existence of an adjacent reference area (grassland or fallow, usually with coconut). Out of these, seven sites were selected. The selected rainforestation sites are shown in fig. 22; most of them are situated on volcanic soils (formed from volcanic ashes or basaltic parent material; Asio, personal communication) with the exception of a limestone soil in Punta. All plots had been installed between 1993-96 on medium- to high-gradient hills, which were used mainly for coconut production or fallowed before. Profile pits and sampling were mostly on the middle slope, with one exception (plateau, see table 5).

Information on land use history of the plantations and reference areas was obtained from interviews with the landowners. Tenurial status, land-use history, agricultural practices and particular information on plants and soil where recorded during interviews with farmers at the time of the first field visit and completed through semi-structured interviews using questionnaires read and filled by the interviewer. Oral history normally goes back until adults' grandfathers' generation, which coincides with Japanese occupation during the Second World War and, sometimes, first clearing of the land. Important incidents such as land reform under Marcos (1972), the Comprehensive Agrarian Reform under C. Aquino (1988) or the Ormoc flashflood disaster (1991) served as reference years for oral history reports.

Figure 22: Locations of research sites

General information on the sites is given in table 5. Details are shown under results in section 3.

Table 5: General information on research sites

#	Location	Planted [year]	Exposition	Slope [%]	Size [ha]	Parent material	Soil unit (FAO)
1	Cienda Demo	1996	S	3-5	1	Volcanic	Dystric Nitisol
2	Patag	1993-4	WNW	75	1	Volcanic	Stagnic Cambisol
3	Marcos	1995	W	60	0.3	Volcanic	Ferri-stagnic Luvisol
4	LSU	1993-5	SW	70	2	Volcanic	Chromic Cambisol
5	Pangasugan	1996-97	WSW	40	0.6	Volcanic	Ferri-chromic Luvisol
6	Maitum	'Early 1990s'	NW	15-75	0.5	Volcanic	Hypereutric Cambisol
7	Punta	'Early 1990s'	WNW	50-150	5.4	Limestone	Calcari-mollic Leptosol

2.3 Land-use history and plot installation in Cienda

Site selection criteria for the new system to be planted were low small-scale variability (as far as possible), comparability with the old rainforestation sites with respect to soil, exposition and slope, as well as a motivated owner experienced with establishment and maintenance of reforestation sites and willing to cede an area sufficient in size to a research experiment for long-term observations. Cienda San Vicente Farmers Association (CSVFA) seemed to fit the latter criteria and a Memorandum of Agreement on cooperation was signed. A plot with homogeneous planting lay-out was then planned and established from March-April 2004 in Cienda as a participatory research project.

Plot position is N10°43'52.1'', E124°48'43.2'', about 300m distant from the plot installed in 1996, and size about one hectare. The area was completely cleared for the first time in 1950 and has since been planted to coconut and banana. In 1971 the present owners inherited the land and divided it along slope direction into two properties.

On the northward side, land-use was continued as before; fertiliser or pesticides were not used. Banana is mainly grown in the centre part of the plot, a large fraction infested by Moko, a bacterial disease (*Rolstonia solanacearum*). Coconut was planted irregularly in time and space with an average distance of 8-10m. Usually, small amounts of coconut husks are burned to repel mosquitoes during harvest time, only once a wildfire struck the entire plot during a dry summer in the late 1980s. The lower part was sporadically browsed by a neighbour's water buffalo, it is characterised by water-logging in one part, indicated by *Wedelia biflora*, and *Imperata sp*. and ferns in the drier parts. In small strips along the lower boundary as well as on some patches in the centre cassava and sweet potato were planted in 2003. Extraction is minimal; three times per year 500-1000kg copra and 30kg bananas monthly are harvested, tubers were negligible. Apart from this, villagers take advantage of the remote situation and extract firewood and coconuts.

The southward half has been managed even more extensively if at all. The area is covered by 7-12m high forest regeneration, mainly *Ficus spp.*, in an early successional stage. Scattered bananas can be found in the plot centre and coconut palms are planted in similar distances as on the other half. With respect to land-use, this side is the more homogeneous. Main differences between both sides are canopy cover (denser in the southern half) and water-logging in the lower part of the northern half. Slope is similar on both sides (20-30%).

2.3.1 Species and planting material

Aiming at a planting scheme comparable to the original rainforestation idea – i.e. with a focus on indigenous timber species – but with more emphasis on early yielding fruit trees, four timber and six fruit tree species were selected. Characteristics of these species as far as relevant for model parametrisation and performance are compiled below[32].

- *Dipterocarpus validus* Blume

syn. *Dipterocarpus warburgii* Brandis, Dipterocarpaceae:

Hagakhak or Apitong Hagakhak is a slender tree (with canopy diameter in solitary stand up to 10m; Fernandez, pers. comm.) with straight bole of up to 50m height (Soerianegara et al. 1993). Branches grow horizontally to downward, leaves are entire, oblong-elliptical, 7.5-12cm x 12-30cm and brownish when young. Wood specific gravity is 612-740kg/m^3 (Soerianegara et al. 1993). Flowering starts at about 10 years age (own observation) from Mar-May, fruits are mature in Sep-Oct (Fernandez, pers. comm.). Hagakhak prefers half-shaded conditions during the first years and can survive even under full shade, but like

32 Not all synonyms are mentioned. Wood specific gravity refers to moisture contents of 15%.

most dipterocarps will grow at a maximum rate only under higher light intensity (MARGRAF & MILAN 1996).
According to WHITFORD (1911) and LANGENBERGER (2003), hagakhak was the dominating species of the Lauan-Hagakhak type forest, which extended from well drained sea-level areas next to the beach forest habitat up to approx. 150m asl., especially along rivers and on gravel. The mostly evergreen species is adapted to a short or no dry season and tolerates short periods of flooding. Other species adapted to the same ecosystem are *Toona calantas* (s. below), *Dracontomelon dao* (Dao), *Terminalia microcarpa* (Kalumpit); erect palms, lianas and small trees are also typical members of the Lauan-Hagakhak forest.
Hagakhak seedlings in PE bags of approximately one year age were provided in good shape by the LSU tree nursery. Average height at the time of the first inventory shortly after planting (June 2004) was 29cm.

- *Shorea palosapis* (Blanco) Merr.

syn. *S. squamata* (Turcz.) Benth. & Hook. f. ex A. DC., Dipterocarpaceae
Palosapis or Mayapis is a fast-growing dipterocarp of up to 50m height with straight bole. Leaves measure 12-24 x 8-11cm (SOERIANEGARA ET AL. 1993), are entire, light green and show a characteristic vein pattern. Flowering season is Mar-May, fruits mature from Oct-Nov; first flowering and fruiting were observed at an age of 10a (FERNANDEZ, pers. comm.). Wood density has been reported to be 310-578kg/m^3 (SOERIANEGARA ET AL. 1993), or slightly above (CABI TREE COMPENDIUM 2002). Under the group name of light red Philippine mahogany, *S. palosapis* as a hardwood is used for construction, posts, furniture, containers and plywood, but has been over-exploited in its natural habitat.
In the Philippines, palosapis grows naturally from sea level up to 300m asl. The species is adapted to uniform rainfall pattern, but tolerates a dry season of up to 3 months. Requirements to soil seem to be medium, but free drainage considered to be important (CABI TREE COMPENDIUM 2002).
Planting material was obtained from LSU tree nursery; average height was 29cm and plants were in good condition.

- *Shorea contorta* S. Vidal

syn. *Pentacme contorta* (S. Vidal) Merr. & Rolfe, Dipterocarpaceae
White Lauan is a large tree of up to 50m height with conical canopy of 15-25m diameter (FERNANDEZ; LANGENBERGER pers. comm.). Leaves are ovate-lanceolate (cordate) and 9-29 x 5.5-11cm in area. Flowers appear from Mar-May and develop into mature fruits until Sep-Oct. First flowering has been observed by FERNANDEZ after 11 years. Wood density is between 420 and 590kg/m^3 (ICRAF online wood density data base[33]).
White Lauan is representative of Yakal – Lauan and Lauan type forests, relicts of which were still found on a plateau area with deeply weathered soil such as under the Cienda demo farm (LANGENBERGER 2003). Lauan forest species are best adapted to climates without or with only short dry periods, but for white lauan up to 5 months of dry periods are reported to be tolerable (CABI TREE COMPENDIUM 2002). With respect to soils, white lauan is not exigent; they may be shallow, but should be free draining.
Under the trade name of Philippine mahogany, white lauan is a highly demanded hardwood timber used for construction, furniture, boats, plywood and pulp.
Planting material was bought from a farmers' cooperative in Patag; some plants were apparently weak and had been uprooted just before being potted in PE bags for sale. Coefficient of variance with respect to height and stem diameter was exceptionally high (43cm and 37%, respectively) indicating great heterogeneity of the planting material. The lowest individual measured only 18cm, the tallest 75cm (average 36cm).

33 www.worldagroforestry.org

- *Toona calantas* Merr. & Rolfe

syn. *Cedrela calantas* (Merr. & Rolfe) Burkill, Meliaceae
Kalantas is a fast growing species common for Lauan-Hagakhak type forests; Kolb (2003) characterises kalantas as a pioneer tree. The species was recommended for reforestation purposes in the Philippines as early as 1916 (Pulhin et al. in Chokkalingam et al. 2006) . The leaves are odd pinnate and up to 50cm long, each dark green leaflet measuring approx. 5-10cm. The tree forms a straight bole of about 25m, up to 20m branchless (Soerianegara et al. 1993) and with a crown diameter of up to 10m. Flowering starts at an age of 6-10 years (Fernandez; Langenberger, pers. comm.) from Mar-May and fruits mature until Aug-Sep. Wood density is 365kg/m^3.
Seedlings obtained from LSU tree nursery were in good shape and measured 41cm in average.

- *Nephelium lappaceum* L., Sapindaceae

Rambutan is a small (Rehm & Espig 1996) fruit tree of 12-25m height (FAO 1982), cloned material often only 4-7m (Verheij & Coronel 1991), with a dense, round canopy (Schütt et al. 2004). Leaves are petioled, alternate or subopposite paripinnate, up to 6-jugate (Verheij & Coronel 1991) with obovate (to ovate) leaflets, which turn from an early brownish stage to dull dark green (Schütt et al. 2004). Flowering starts from the 5th to 6th year (for budded plants earlier) and takes place during dry season (Verheij & Coronel 1991), the fruit ripening within 90-150d later (Schütt et al. 2004). The fruit is bright red, ellipsoidal in shape, measures 3-4 x 6cm and bears soft hooks on the outside. The white arils are edible and commercialised, the seed contains about 30-45% fat and can be eaten roasted (FAO 1982). Wood density is 1001kg/m^3 (Schütt et al. 2004).
In the Malay Archipelago as its area of origin (FAO 1982) and also in Thailand, rambutan production is highly commercial and many different varieties have been bred. Most of the improved varieties are grafted. Yields range from 25-30kg/tree (own estimation after Verheij & Coronel 1991 and interviews with farmers) to 48-120kg/tree (Schütt et al. 2004, data from the Philippines). Figures for maximum production under optimal conditions are given by Verheij & Coronel (1991) with up to 170kg/tree from the 8th to 10th year and even 250-300kg/tree have been reported (FAO 1982).
Rambutan has been classified as medium-sized gap species, which tolerates light shade. However, in orchards and plantations it is usually planted under open conditions. As ecological optimum for rambutan, Schütt et al. (2004) give the example of Mindoro Oriental with 1800mm evenly distributed annual rainfall, 27.3°C annual mean air temperature and 82% relative humidity. A dry season > 3 months as well as strong wind during flowering are noxious. According to FAO (1982), infertile soils are tolerated as long as rooting depth is sufficient.
Grafted planting material was obtained from a commercial tree nursery specialised on import of fruit trees from Mindanao. Plants were strong and already overgrown in 1l PE bags. Initial height was 154cm in average, habitus was not balanced. Trees appeared as if kept in very dense stand in the nursery. After planting out many plants bent down and a new sapling from below took the lead.

- *Durio zibethinus* Murray, Bombacaceae

Durian is a tall tree (up to 35m) with straight bole, conical and dense crown formed by mainly horizontal branches (FAO 1982). Crown diameter is estimated approx. 15m. Leave position is alternate to subopposite, they are petioled, simple, entire, ellipsoid-lanceolate and acuminate. The upper surface colour varies among sites, the lower side is silver to brownish/copper. Flower is induced by dry season and two flowering periods per year are reported (FAO 1982). Yellow to pale brown round to ellipsoidal spiny fruits form 90-130 days after flowering (Verheij & Coronel 1991). They weigh 2-3kg and are approx. 20-35 x

17cm in size. Wood density is 540 (FAO 1982) to 690kg/m^3 (Schütt et al. 2004), the timber being used for light construction.
Durian is native to Malaysia where it grows naturally on forest margins up to 300m asl. It prefers half-shaded conditions, can survive under full shade, but grows only, under higher light intensity. The fruit is said to be promising with respect to commercialisation and many improved varieties have been developed. Yields start from the 5th to 7th year after planting (FAO 1982) and amount to 50 fruits/tree (FAO 1982; Verheij & Coronel 1991).
Grafted plants from Mindanao were bought at a commercial nursery. Seedlings were uniform (average height 86cm) and in excellent shape.

- *Garcinia mangostana* L., Clusiaceae (=Guttiferae)

Mangosteen is a relatively small tree, 6-25m (PROSEA) tall, but in cultivation mostly smaller than 10m and 0.25-0.35m stem diameter (FAO 1982). Perfectly symmetrical growth and conical crown are characteristic for its architecture. Like branches, leaves are always opposite; they are petioled and elliptic to oblong in shape, measuring 12-23 x 4.5-10cm. Due to its poorly developed root system (FAO 1995), the plant is said not to be an efficient nutrient acquirer, which would be an explanation for the very slow development. Flowering is induced by a dry period. Only from the 10th to 15th year after planting, production of fruits starts, maximum yield can be expected after 20 years. The fruit is a purple berry of 5-7cm diameter (FAO 1982) containing white edible arils and a seed, which is edible when roasted. Wood is heavy, its density just below 1000kg/m^3 (FAO).
G. mangostana is high in demand in Thailand and Malaysia, where most progress in plant breeding has been achieved. Seeds or cuttings are used for propagation; grafting on other *Garcinia* species is common. As an average fruit yield for the Philippines, 1.8-2t/ha have been reported (FAO 1982).
Mangosteen stems from the Sunda Islands and Malay Peninsula (FAO 1982). It grows well in clayey unless water-logging soils. As an understorey species, mangosteen still performs well under up to 50% shade; shelter from wind and sun is necessary.
Plants were bought from a commercial tree nursery. Material was uniform and healthy, average was 30cm. Seedlings had been kept in a strongly shaded bed and already suffered during the short accommodation to a brighter place before transplanting.

- *Lansium domesticum* Corr., Meliaceae:

Lansones is a short-trunked tree of 10-15m height. Leaves are pinnate, 22.5-50 cm long, with 5-7 alternate, elliptic-oblong leaflets. Fruits are greyish-yellow, 2.5-5 cm in diameter and are borne in clusters. Fruiting starts after 12-20years, if trees are grown from seeds. (ICRAF online AgroforesTree database)Wood density ranges from 750-920kg/m^3 (ICRAF online wood density data base).
Lansones is native to Malaysia and common throughout Southeast Asia. The natural habitat is limited to areas lower than 700m asl and without pronounced dry periods. Lansones grow best under half-shade on humic and free draining soils and are highly sensitive to water-logging.
Propagation is by seed, whereby viability lasts few days only. Grafting is common. Average yields in the Philippines are around 1000 fruits per tree (ICRAF online AgroforesTree database).
Planting materials of about one year age were purchased at a commercial tree nursery. Plants were not too uniform (average height 46cm, span 6-62cm) and yellow leaves indicated a suboptimal health status.

- *Artocarpus heterophyllus* Lam., syn. *Artocarpus philippensis* Lam., Moraceae:

Jackfruit is a medium-sized evergreen tree of 15m height and trunk diameter of 0.3-0.5m. Leaves are alternate, stipulate, entire and of elliptical shape. They measure 10-20 x

3-12cm. The tree is cauliflor, flowers being formed from the 2nd - 6th year after planting (Brack Egg, 1999). Individual fruits can weigh 10-30kg. Maximum production is reached from 8th to 15th year onward, attaining 12-100 fruits (Brack Egg 1999) or 250-750kg/tree/a. The wood is used for construction, furniture, handles and dye. Specific gravity is 420-700kg/m^3 (ICRAF online wood density data base). Many varieties are known.
Jackfruit is a lowland species native to India (CABI Tree Compendium) and characterised as medium-sized gap species. Seedlings tolerate light shade but grow best in full sunlight. In the rainforestation inventories of Kolb (2003), Jackfruit was the fastest growing fruit tree. Shallow soils are tolerated unless they are water-logging (FAO 1982).
Healthy and very uniform grafted plants (average height 63cm) were purchased at a government-operated nursery in Balinsasayao, approx. 30km SE from LSU.

- *Artocarpus odoratissimus* Blanco, Moraceae (synonymously *A. odoratissima*):

Marang is an evergreen tree, up to 25m tall. Leaves are broadly elliptic or rhombic to obovate, 16-50 cm x 11-28 cm, with the upper half often 3-lobed; both surfaces are hairy. Fruits are subglobose, up to 16 cm x 13 cm, green-yellow, their flesh is white, juicy and fragrant. (ICRAF online AgroforesTree database). Fruiting season is from Aug-Dec (Mindanao) and flowering starts from the 4th to 6th year. Wood density is 580-780kg/m^3 (ICRAF online wood density data base).
Fruits are said to be superior in taste to jackfruit, but harvest is difficult and shelf life short. Seeds are edible when cooked. Marang stems from Borneo, but is widely cultivated in the Philippines. Its natural habitat are partly-shaded places in secondary forests from 0-800m asl in regions with evenly distributed rainfall. The tree grows best on rich loamy, well drained soils. Propagation by seed is easy with high germination rates, growth is fast and major pests and diseases have not been observed.
Seedlings were uprooted wildlings from the rainforestation demo site in Cienda and brought by a CSVFA member. Age at planting time was estimated about 6 months, initial height was 15cm in average with high heterogeneity between individuals (coefficient of variance 35%).

- *Musa textilis* Nee, Musaceae

Abaca is botanically closely related to banana and similar in habitus. In contrast, abaca pseudostems are more slender and often reddish, the leaves are narrower, not rounded at the end and show a dark line on the upper leaf surface.
Abaca is a typical shade-tolerant understorey plant. It is traditionally planted either under existing forest canopy or along forest margins, but can be cultivated in pure stands in open areas, if continuous weed management and soil cover are provided. Planting is best at the onset of the wetter season (for Leyte Jul-Aug) as evenly distributed rainfall is crucial for abaca. With respect to soil, the species is not demanding, but volcanic soil rich in humic matter are preferred (FIDA extension material, not dated).
Propagation can theoretically be by seed or tissue culture, but cormus propagation (suckers) is most common. First fibre harvest is after 18-24 months and then every 3-4 months. The fruits are not edible.
Most relevant diseases for abaca are viruses like bunchy top and abaca mosaic, which are transmitted by aphids like *Pentalonia nigronervosa* among others. Besides, *Fusarium oxysporum* and bacterial wilt (*Ralstonia solanacearum*) are relevant (Borines & Palermo 2006).
Abaca or manila hemp leaf sheaths render a very resistant fibre used for cordage, pulp or craftswork made of fibre (Brown 1919). The plant is expected to have some economic potential on the world market and efforts are made to improve properties, processing and cultivation (e.g. Guarte & Sinon 2005). The Visayas and Mindanao are the most important regions of abaca production in the Philippines, which are the only country worldwide to

produce considerable quantities of abaca fibres (minor production exists in Ecuador). Within the Visayas, Southern Leyte is an important centre of abaca production. For Leyte, abaca is the second most important agricultural product for export after copra. Different traditional and some improved varieties are available, the most popular among farmers in Baybay being Inosa. Other varieties are Laylay (promoted by the National Abaca Research Centre, NARC, at LSU), Musatex 80, 81 and 82 and Minenonga (recommended by FIDA) as well as local traditional varieties.
Planting material of Laylay and Inosa varieties was purchased from tissue culture produced at NARC. The decision to use this kind of planting material was rather because of missing alternatives than to obtain virus-free plants: According to CSVFA members suckers of Inosa or other traditional varieties could not be obtained at the time of plot installation. At NARC supply was low, so that two different kinds and to some extent small plantlets (height about 10cm) had to be accepted.

2.3.2 Plot design

The planting lay-out is based on a 10 x 10m grid of alternating timber trees, with interplanted fruit trees at 5 x 5m distance. In between, *M. textilis* was planted at 2.5m distance (see fig.23). Cover crops and annuals were not planted, first, because soil protection from erosion seemed to be ensured by present *Pueraria phaseoloides* and other creepers, and secondly, because farmers considered the plots too distant from the village for planting, maintaining and harvesting annuals.

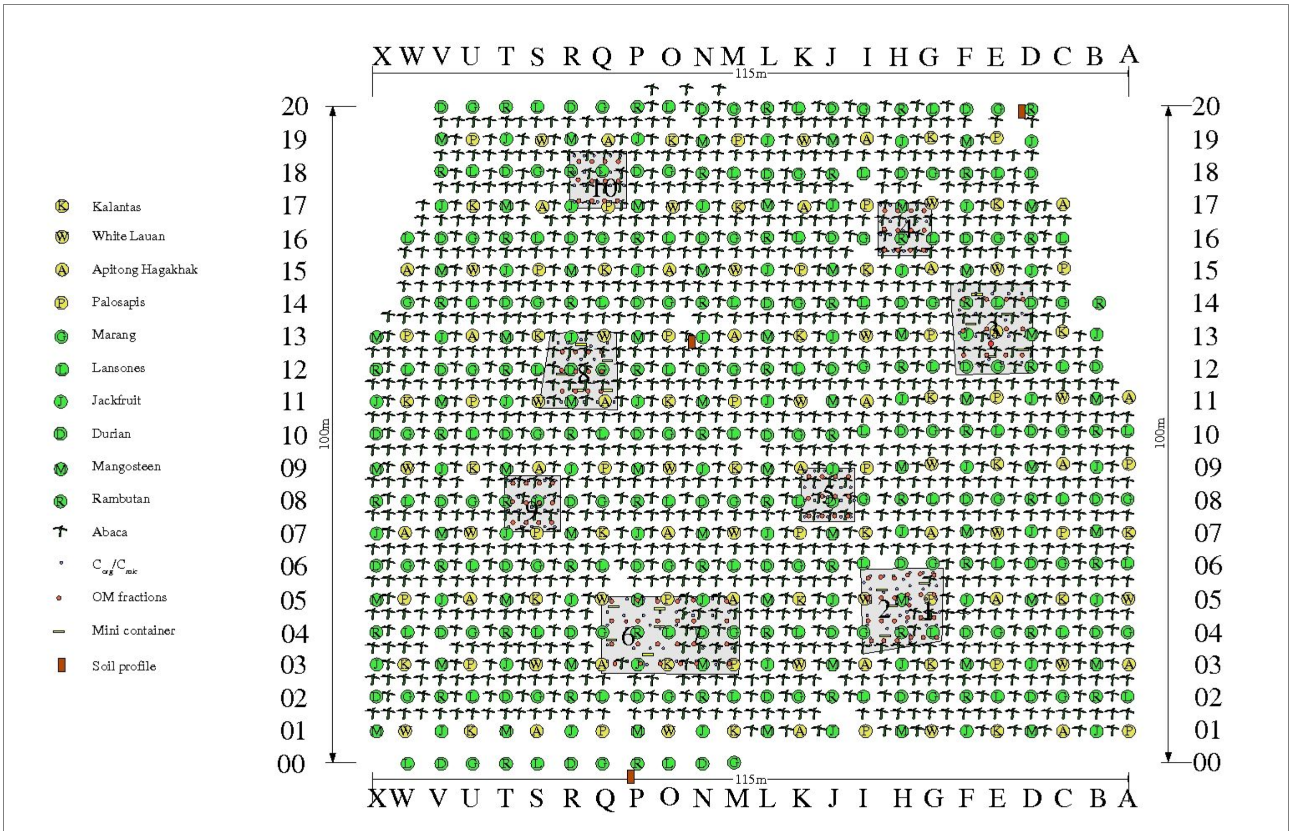

Figure 23: Planting scheme new plot in Cienda

All species were planted in a regular sequence along all slope positions and previous land-uses to facilitate evaluation of their performance under all given conditions. The two areas without abaca planted (corresponding to subplots 2 and 6, s. below) were intended as controls to compare effects of abaca growth to adjacent subplots 1 and 7.

2.4 Meteorological data

2.4.1 Weather data

Weather data were obtained from the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA). The meteorological station is situated on LSU campus at 7m asl. The data cover the period from 1999 to April 2006 on a daily basis, including minimum and maximum air temperature [°C], relative humidity [%], rainfall [mm], wind speed [ms^{-1}] and direction [1], potential (pan) evaporation [mm] and bright sunshine [min]. Pan evaporation was evaluated using the Penman equation on the basis of PAGASA observations.
As the experimental plot in Cienda is located at >100m elevation, approximately 5km from LSU on the western footslopes of the cordillera, a portable weather station was installed at Cienda village in April 2004 for comparison. This µMetos (Pessl) device logged hourly air temperature, relative humidity, rainfall and wind speed in the same units as PAGASA and additionally solar radiation [Wm^{-2}]. These data were then used for comparisons between both sites.
Tiny Talk II sensors (Gemini) and loggers were used for registration of soil temperature. Measurements were conducted on site under different vegetation types in 5cm soil depth and covered time spans from 24h up to 2 months. On the basis of these data, regressions were calculated to predict Cienda soil temperature from PAGASA-LSU air temperature and rainfall.

2.4.2 PAR measurements

In order to assess the impact of radiation on plant growth and mortality, Photosynthetically Active Radiation (PAR) was measured with ecotec PAR 750 sensors and stored in DL424 data loggers (all by Colorlite). Measurements were carried out on the Cienda plot during cloud-free midday hours as singular measurements. Four sensors were used simultaneously: Two stationary reference sensors under open sky in five and one meter height, respectively, and two mobile sensors in one meter distance mounted on a slat to maintain a horizontal position. The latter were carried to each of the 400 tree positions and held over the tree denoting exact time of measurements. Later a mean of the two mobile sensors, accounting for small-scale variation, was related to the simultaneous reference values and the PAR value expressed as percentage of PAR above canopy. As sun flecks play an important role under closed canopy (Kellman 1970; see also fig.24), integrated measurements of high temporal resolution would have been desirable for each spot. As this was not possible, representative places on the plot were observed, usually during 48h in time-steps of 2s. These observations were extended to the nearby 10-year old rainforestation site in Cienda and additionally included air temperature and relative humidity (sensors were ecotec TLM 35 for temperature, FLM 15-ME (both Colorlite) for relative humidity).

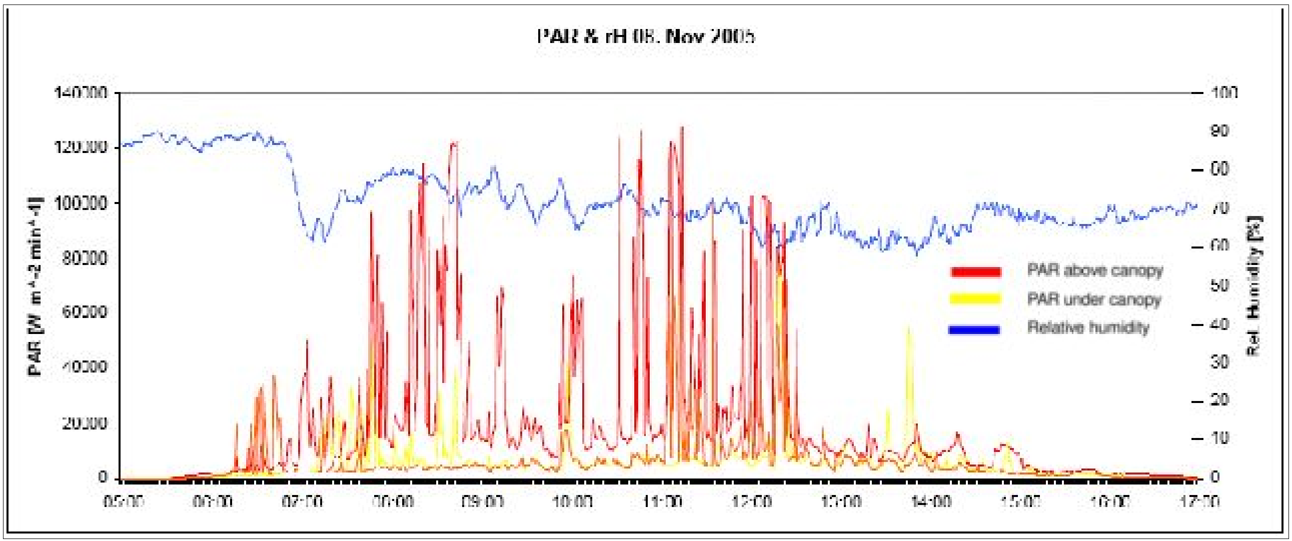

Figure 24: PAR in an open area and under canopy and relative humidity intraday during one day in the rainy season 2005

2.5 Soil analyses

As far as not otherwise stated, fine earth refers to soil sieved through a 2mm sieve and all results are expressed on an oven-dry basis.

2.5.1 Subplots and sampling scheme

In Cienda, ten subplots were established after an exploratory auger transect assessment to account for small-scale variability. These subplots were used for further soil sampling and positioned in order to represent different canopy cover, slope position and land-use history due to tenure. Subplots 1 & 2 and 6 & 7, apart from being different treatments with respect to abaca later, served as quality and sensitivity checks for soil analyses during the first months.

For the paired plot approach, adjacent areas were sampled in representative zones. Obviously disturbed zones like footpaths, eroded soil, burnt areas, piles of harvested coconut husks etc. as well as plot margins were excluded from sampling.

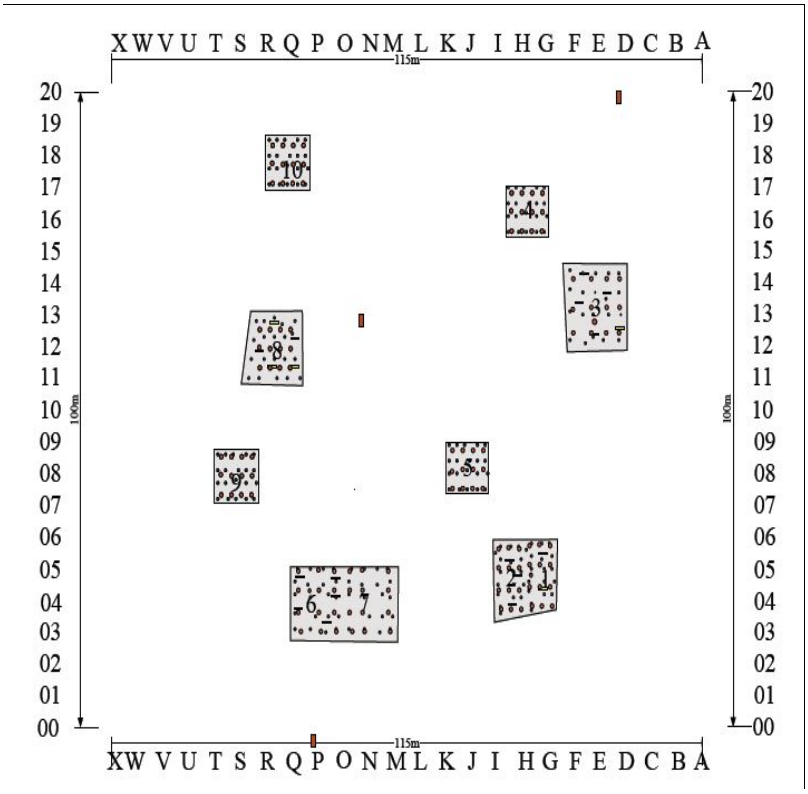

Figure 25: Subplots and sampling scheme new plots Cienda

2.5.2 Soil profiles

For selection of representative profiling points, auger samples were taken along transects covering different slope positions and relief forms. For general classification and characterisation one profile was then dug in each rainforestation area per site. For the new plantation in Cienda, a more detailed scheme included three profiles along a transect in different slope positions. Profiles were dug to a depth of 1m according to FAO procedures, but with a reduced profile area of approx. 1x1.2m to minimise root damages in the plantations.

2.5.3 Soil sampling

In Cienda, the ten established subplots were used for a first assessment of variability with respect to C_{org}. These plots were retained for further analyses.
For the paired plots, different sampling approaches were tested with respect to deviations. These always aimed to representatively cover the entire plot and ranged from eight single samples per plot up to five composite samples containing 20 nested individual samples each. All analyses concerning the paired plot approach were subsequently carried out on the same samples.

2.5.4 pH

pH of field fresh soil was measured in $H_2O_{dist.}$, 0.01M $CaCl_2$ and 1M KCl using a Corning 10 and, in 2006, a Metrohm 826 pH-meter. Control measurements were carried out in Hohenheim in 2005 (in air dry samples).
In all cases, ratios were 10g soil : 25ml of solution/water. Measurements were conducted 30min after homogenising the solution with a plastic rod.

2.5.5 Bulk density and volumetric water contents

Aluminium cylinders of 100cm^3 volume were used to determine bulk density and $WC_{vol.}$ as described in Schlichting, Blume & Stahr (1995). Gravimetric water contents could then be transformed into volumetric values. For each soil horizon, an average out of 3 replicates was calculated.

2.5.6 Gravimetric water contents and soil water potential

Self-made FDR sensors (Frequency Domain Reflectometry, see fig.26) were used to estimate soil moisture. Principally, frequency of a swinging capacitor differs depending (exponentially) on water contents of soil located between the two conductor plates. This frequency can be converted into voltage and read out using a common household multimeter.
In direct vicinity of profiles Cienda PN1 (middle slope closed canopy) and PN3 (footslope open area), sensors were installed in four depths per profile corresponding to the vertical centre of each horizon (none in the stony C horizon of PN1). Two to three sensors were installed per depth, horizontally in the three upper and – for technical reasons – slightly inclined in the lowest horizon. Calibration of all FDR devices had been carried out in the laboratory with air, oven-dried soil, rewetted soil of 5, 10, 15, 20% gravimetric water contents and water. For each sensor an individual calibration curve was plotted from measurements in sandy soil to avoid influence of compaction. As this proved not representative for clayey Cienda soils (field capacity was exceeded at < 20% gravimetric water contents) and calibration with clayey soil would have caused other types of artefacts, calibration was undertaken through gravimetric water content measurements

(auger method) carried out simultaneously to FDR and tensiometer readings during representative weather conditions.

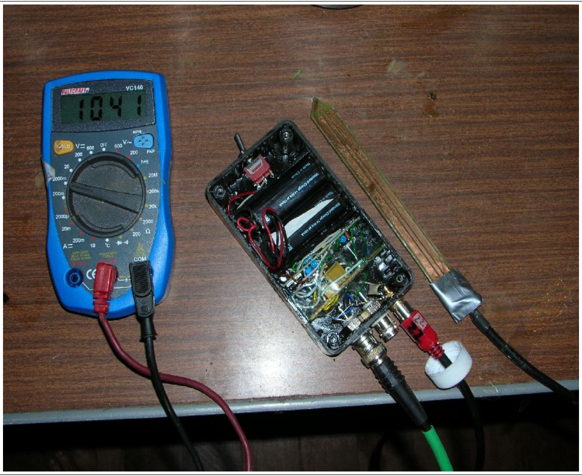

Figure 26: FDR sensor

Two tensiometers per horizon, extended with rubber hose (joints fixed with clamps and sealed with epoxy resin), were installed next to the FDR pits.
After augering holes to the depth aimed for, extracted soil suspended in water was poured into the hole before inserting the tensiometer; thus a tight contact between the ceramic head and soil matrix should be achieved (Hartge & Horn 1989). Distilled boiled water was filled into each tensiometer, which was then closed with a rubber septum. Hoses ended shortly above ground level and readings were always carried out during the morning hours, before the high rising sun would have led to expansion of the water column (Schlichting, Blume & Stahr 1995). Tensiometers were mantled by a plastic collar to keep rain water from entering the holes and septa were protected with aluminium foil against heat and rodents. For readings a digital differential pressure manometer (Greisinger GDH 200-13) connected to an injection needle to penetrate the septum was used. Simplified, matrix potential, not taking into account osmotic and pressure potential, was calculated as

$$\Psi_M = -|\Psi_H| - |\Psi_z|$$

Ψ_M = matrix potential (negative value above groundwater level) and Ψ_z = gravitation potential. Gravitation potential Ψ_z was converted from depth as 1cm water column = 98.0665 Pa. The top ground surface was taken as reference level. Pressures were log10 transformed and expressed as pF.
In addition, gravimetric water contents were measured from auger samples of the same spots and depths periodically, especially during extreme conditions. Kellman (1970) mentions, that soil water dynamics are more strongly influenced by rainfall events than by seasons. Measurements were thus conducted event-specific from Feb-May 2006, i.e. during the transition from rainy into dry season. Initially, three samples per horizon were bulked, but after an obvious weighing error (Feb 13th, horizon 5-14, PN3) three individual samples were gathered per horizon and plot.

2.5.7 Particle size distribution

Particle Size Analysis was carried out at Dept. of Soil Sciences in Hohenheim following a standard procedure. Weight of air-dried samples was 20g. For samples with pH $CaCl_2$ > 6.5, carbonate destruction (using HCl) was carried out first; where SOM exceeded 1%, destruction of humic matter in H_2O_2 at increasing temperatures (stepwise up to 80°C) was necessary as a pre-treatment. In a following step, H_2O_2 was removed with water. Once electric conductivity was below 40µS, analysis was carried out following the sieving-pipetting procedure given by Schlichting, Blume & Stahr (1995). As Cienda samples sedimented too fast for pipetting of clay, they were shaken in NH_3 solution during one week (instead of just overnight) for dispersion.

2.5.8 Total nitrogen

Analysis for soils as well as fractionated organic matter (s. 2.5.14) was carried out in 1g finely ground air-dried samples with a C-N analyser.

2.5.9 Phosphorus

Generally, Bray II method was preferred as it would allow extraction of occluded and aluminium- as well as calcium-bound P_I from acidic and calcareous soils, respectively. Moreover, for the calcareous soil in Punta, P extracted with Olsen's procedure ($NaCO_3$) was not detectable.

Topsoils for the paired plot experiment were analysed in 2005 at LSU root crops laboratory according to Bray II method (as described by PAGEL ET AL. 1982), using ascorbic acid as a colourant. Where the filtrate interfered in its natural colour with the ascorbic acid complex, it was first cleared with activated charcoal. For samples showing very low P contents, sample weight was doubled for a second run. Readings were taken at 880nm using a Hitachi U-2000 spectrophotometer.

P_I of profile samples was analysed 2006 at LSU following the Soil Research Test Plant Analysis Laboratory (SRTPAL) standard procedure, which is based on the Bray II method. Bray solution is made of 1.11g solid NH_4F dissolved in 0.1N HCl (gives 0.03N NH_4F). For the colouring agent, the following stock solutions are prepared: 1 litre of solution A contains 5.35g ammonium molybdate and 0.12925 potassium antimony tartrate (dissolved separately) plus 66ml concentrated H_2SO_4. Solution B is prepared of 2.0922g ascorbic acid dissolved in 1l distilled water. A 4:1 mixture of B and A solution then gives the colourant. Standards are made of KH_2PO_4. 2.5g of ground soil were extracted with 25ml Bray II solution (shaking them during 5min), filtered (Whatman 42) and 10ml colourant were added to a 2ml filtrate aliquot. Transmittance was read at 880nm in a Bausch and Lomb Spectronic 20 fotometer.

For Cienda profile samples P_{org} was determined after SCHLICHTING, BLUME & STAHR (1995) as difference of 0.1N H_2SO_4 extracted P of ashed and non-ashed samples. This method basically corresponds to Truog's method (extractant 0.002N H_2SO_4) as described by PAGEL ET AL. (1982). For SOM fractions, ICP-OES element analysis was chosen after HCl/HNO_3 extraction.

2.5.10 CEC_{eff}, CEC_{pot} and base saturation

Potential Cation Exchange Capacity (CEC_{pot}) describes the amount of exchange sites for cations in a soil at a buffered pH of 7.0, while effective CEC refers to a soil at its natural pH. Both were analysed as described by SCHLICHTING, BLUME & STAHR (1995). For CEC_{pot} cations were displaced with Na- and NH_4 -acetate. For CEC_{eff}, cations in 10g of fine earth were exchanged by 100ml 1M NH_4Cl and percolated with $BaCl_2$. Ba^{2+} was then replaced by H^+ from HCl and quantified with a flame fotometer at 873nm. CEC_{eff} and CEC_{pot} were computed as

$$CEC_{eff/pot}[cmol_c/kg]=\frac{(Abs._{sample}-Abs._{blank})\,x\,100\,x\,\text{vol. flask [ml]}\,x\,\text{dilution}}{1000\,x\,\text{weight sample [g]}\,x\,meq}$$

where for CEC_{pot} meq refers to the exchange solution and for CEC_{eff} to the respective cation.

Base saturation was calculated as the ratio of basic cations (S-value) to potential CEC:

$$BS\ [\%]=\frac{S}{CEC_{pot}}$$

Aluminium saturation was calculated as Al^{3+} / S-value.

2.5.11 Exchangeable basic cations

Plant-available Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} were determined for top soil samples (0-20cm) of the paired plot experiment. Analysis was carried out April 2005 at root crops laboratory, LSU.
2.5g of air-dry fine earth were mixed with 25ml 1N ammonium-acetate adjusted to pH7, shaken for 5min and passed through Whatman 42 filter papers. For detection the AAS (Varian 220FS) was run with air/acetylene and set to 422.7nm for Ca^{2+}, 285.2nm for Mg^{2+}, 769.9nm for K^{+} and 589nm for Na^{+}. Concentration of the respective cation in the extractant was then computed using a calibration curve produced from standard solutions.

2.5.12 Pedogenic oxides of Fe, Al and Mn

Oxalate extracts the mobile or 'active' fraction of Fe, Mn and Al oxides such as ferrihydrite, allophane or organo-complexes. Dithionite-citrate extraction is used for crystalline pedogenic forms of Fe, Mn and Al.
For determination of 'active' Fe, Al and Mn contents, 2g of air-dry fine earth were extracted with NH_4 -oxalate solution and filtered as described by Schlichting, Blume & Stahr (1995).
The more stable crystalline pedogenic oxides of Fe, Mn, Al were extracted, centrifugated and decanted with dithionite-citrate solution from 2g of air-dry fine earth according to the procedure given by Schlichting, Blume & Stahr (1995).
Detection was by atomic absorption spectrometry for both extraction solutions (Fe 248.3nm air/acetylene, Mn 279.5nm air/acetylene, Al 309.3nm N_2O/acetylene).

2.5.13 Soil organic carbon

Different methods were employed depending on availability of equipment, research purpose and number of samples. Among the used approaches to analyse C_{org} contents, Loss on Ignition requires least technical expenditure and no chemicals. Walkley-Black method (WB) is standard in many laboratories in tropical countries, but hazardous and pollutant as it makes use of potassium dichromate. Elemental analysis (here: LECO C/N analyser) is most convenient and supposed to deliver the most exact values, which are not influenced by clay contents as is LoI.

2.5.13.1 Loss on Ignition

LoI analysis was based on method descriptions by Schlichting, Blume & Stahr (1995), Pagel et al. (1982) and Agricultural Experiment Stations of Connecticut et al. (1995). Ignition temperature (ranging from 360°C to >800°C in literature) had to be selected sufficiently high to ignite all carbon including charcoal, but on the other hand minimise errors arising from evaporating crystal water.
Crucibles were tared after ignition during 4h in a muffle furnace at 550°C (there was no significant difference between tare weights at 105°C and 550°C). Approximately 5g of air-dried earth were then oven-dried at 105°C until constant weight (12h) and, after cooling down in a desiccator, weighed to mg.
The muffle furnace was pre-heated to 550°C and, once it had reached this temperature, samples were ignited during four hours. After turning off the furnace and cooling down to 250°C, crucibles were transferred into a desiccator and, later on, weighed again.
Soil organic matter was computed as follows:

$$\text{SOM [\%]} = \frac{\text{Gross Weight 105°C [g] - Gross Weight 550°C [g]}}{\text{Gross Weight 105°C [g] - Tare Weight [g]}}$$

and organic carbon as

$$C_{org}[\%] = \frac{SOM\ [\%]}{1.724}$$

2.5.13.2 Elemental analysis

Carbon and nitrogen contents of finely ground profile samples were determined using a LECO C-N analyser. This analysis was carried out at Landesanstalt für Landwirtschaftliche Chemie (LACh), and Dept. of Soil Sciences, Hohenheim.

2.5.13.3 Wet combustion

SRTPAL standard procedure is based on the Walkley-Black method, differing from other wet digestion methods in that Cr^{3+} is quantified by titration, not fotometrically.
0.5g of finely ground soil are weighed in a flask, then 10ml of 1N potassium dichromate ($K_2Cr_2O_7$) and 10ml of concentrated H_2SO_4 are added. After swirling and leaving the flask for one hour, it is supposed, that all organic C has been oxidised, setting a corresponding amount of Cr^{3+} ions free. The remaining $K_2Cr_2O_7$ is backtitrated with 0.5N ferrous sulphate ($FeSO_4$ x $7H_2O$) and 0.025M O-phenanthroline – ferrous complex as an indicator. The reduced Cr^{3+}, which corresponds to the amount of organic C, can then be calculated as fraction of a blank subtracted from 1 as follows:

$$\text{Organic Matter } [\%] = 10\left(1 - \frac{S\ [ml]}{B\ [ml]}\right)\frac{0.69}{\text{Sample Weight } [g]}$$

where S and B are amounts of $FeSO_4$ solution for the titrated sample and blank. The factor 0.69 is derived from

$$1N\ \frac{12}{4000}\ \frac{1.72}{0.75}100\% = 0.69$$

where 1N is the normality of $K_2Cr_2O_7$; 12 / 4000 = meq of carbon, 1.72 conversion of organic C into organic matter and 0.75 an empirical recovery factor for organic C, taking into account, that only a certain proportion (75%, the *easily oxidisable* fraction according to AGRICULTURAL EXPERIMENT STATIONS OF CONNECTICUT ET AL. 1995) of total C_{org} is oxidised.

2.5.13.4 Assessment of methods

Loss on Ignition is simple, efficient and robust, but often said to be of low accuracy due to crystal water bound to clay and oxides, which is accounted for as carbon when weighed. Walkley-Black is claimed by some to be more exact[34] than LoI. Given large numbers of samples, LoI was first choice, after calibration with Walkley-Black and Elemental Analysis.
A general source of error for WB is, that only easily oxidisable C is detected, which is then converted into C_{org} by multiplication with the recovery factor 0.75. On the other hand, recovery from 0.59-0.94 has been observed as a consequence of different temperatures

34 in contrast to SCHLICHTING, BLUME & STAHR (1995): [...] *given the numerous presumptions [for Walkley-Black method], it must appear surprising, that results in most parallel experiments sufficiently match those obtained by elemental analysis* [p.160].

(SRTPAL procedures, unpublished). Chlorides, ferrous iron (Fe^{2+}) as well as organic N or S can also be oxidised and hence lead to overestimation, whereas manganese or oxidised organic C will result in underestimation of C_{org} (SCHLICHTING, BLUME & STAHR 1995). Consequently, AGRICULTURAL EXPERIMENT STATIONS OF CONNECTICUT ET AL. (1995) recommend to collect a representative cross-section of soils from the area under research, calculate a regression Walkley-Black – LoI and continue analyses using only LoI. This regression would not take clay contents into consideration, in contrast to what has been suggested by SCHLICHTING, BLUME & STAHR (1995).
Unlike WB procedure, LoI and other dry combustion methods include all organic carbon but, depending on combustion temperature, also other fractions like crystal water.
Interrelation of LoI and WB was assessed for 20 SRTPAL standard soils from different sites in Leyte (fig.27). As recommended by SCHULTE (1995), a correction factor for clay was not subtracted.

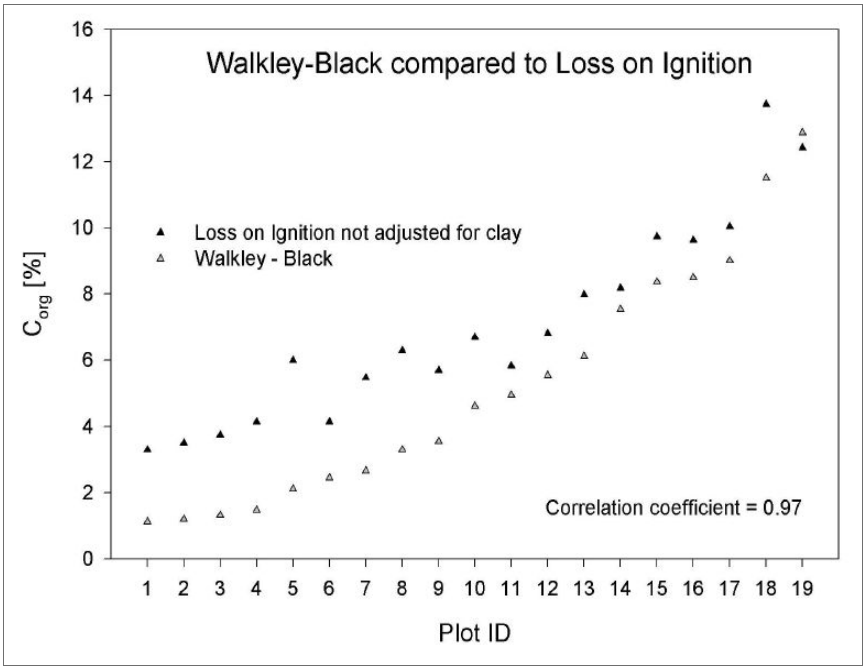

Figure 27: Comparison of C_{LoI} and C_{WB} for 20 Leyte soils

For profile samples, a CN-analyser was available in Hohenheim, so that the relationship between LoI and elemental analysis (EA) was of interest. Samples from the Cienda profiles with known clay contents were analysed, and regressions were calculated with and without the use of a correction factor for clay (subtraction of 0.1% C_{org} per % clay, as suggested by SCHLICHTING, BLUME & STAHR (1995)). This factor resulted in negative values for all horizons rich in clay or low in OM, so that an empiric linear regression including the independent variables C_{LoI} and clay contents was formulated (fig.28).

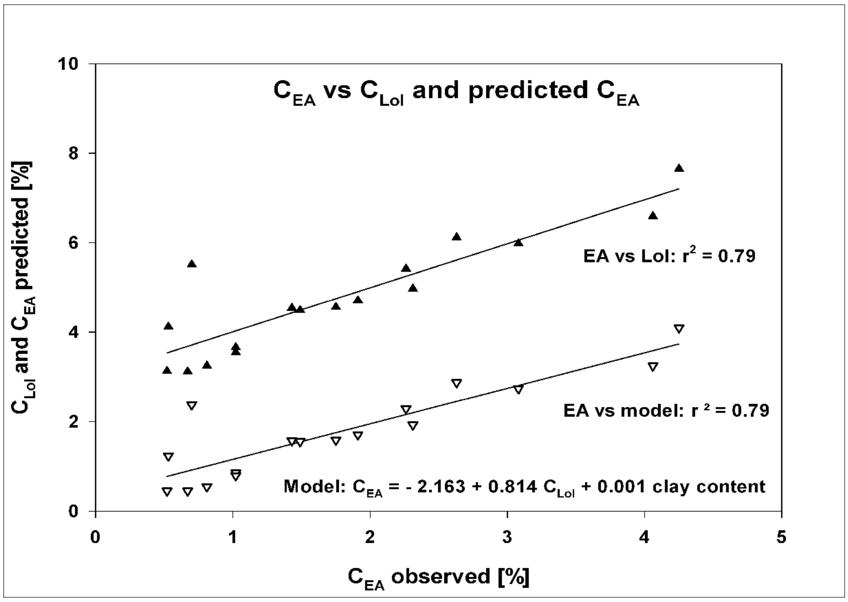

Figure 28: Observed vs predicted values for C_{org} at Cienda profiles

Clay contents did not exercise substantial influence on the dependent model, so that coefficient of determination was $r^2 = 0.79$ for the model as well as for LoI by itself. The formula was used for calculations of C_{org} in chapter 5. After converting SOM_{LoI} into C_{LoI}, C_{org} was calculated as follows:

$$C_{org}\ [\%] = -2.163 + 0.814\ C_{LoI}\ [\%] + 0.001\ \text{clay}\ [\%]$$

The lower C contents of EA may be explained to a minor extent by losses in C contents during storage (approx. 3 months), but the main reason is due to the procedure, as discussed above.

2.5.14 Physical fractionation of soil organic matter

One bulked sample containing 12 cores of almost 600cm^3 each (Eijkelkamp root corer, sampling depth 0-15cm) was collected per subplot. The soil surface was not cleared at sampling time to include the litter layer, yet living aboveground biomass was sorted out as were live roots.

The entire sample was air-dried and sieved to 2mm and the following fractions were separated following the procedure described by GAISER (1993), with some modifications:

The *Light Organic Matter > 2mm fraction* was separated by flotation in water (decantation into a 2mm sieve), segregated manually into aboveground biomass and roots and then dried at 60°C and weighed. C, N and P contents of a subsample were determined. Stones and charcoal fraction > 2mm were also weighed.

To obtain the *Light Organic Matter < 2mm fraction*, 1kg of fine earth was mixed in a pail with roughly 5l of water and stirred well. Floating organic matter was then carefully decanted onto a 0.25mm mesh sieve. This fraction was then washed out of the sieve with a small amount of water. It was dried at 60°C and weighed. A subsample was set aside for C, N and P analysis.

To the remaining rest of *Heavy Organic Matter* + *Mineral Soil < 2mm* and water, 10ml of concentrated HCl were added. This mixture was left overnight for sedimentation and then decanted. A subsample of the sediment was dried and the moisture conversion factor calculated. Carbon, nitrogen and P contents of this fraction were analysed. Elemental analyses were carried out using a C-N analyser and for P an ICP-OES at LACh Hohenheim. Carbon contents of the fractions' subsamples were then multiplied by the respective oven-dry weight of each fraction.

2.5.15 Substrate-Induced Respiration

Substrate Induced Respiration (SIR) method is applied to estimate microbial biomass in soils. After addition of an easily accessible substrate, glucose[35], to a soil sample, the increase in microbial metabolism, expressed as respiration, allows conclusions on the size of the actively metabolising microbial population.
Field-fresh soil samples were stored at 8°C, then passed through a 2mm sieve and remaining roots were picked out with forceps. If the sieved samples could not be analysed immediately, they were stored in a deep-freezer. Prior to incubation, samples were adapted to room temperature during 5 days. In 2004, incubation temperature was approx. 32°C (dry season room temperature), in contrast to the original procedure (ANDERSON & DOMSCH 1978). Only in 2005, an air-conditioned room was available for the paired plot experiments, so that the analysis could be carried out at 22°C as described in most literature. As night topsoil temperatures in Leyte can be as low as 22°C, a shock, drastically reducing metabolism after conditioning at room temperature was not expected. Still, samples were acclimatised to 22°C the morning before the experiment actually started (preparations would usually take until noon). Gravimetric water contents were parallely determined in subsamples after sieving and samples were adjusted to 55% of water holding capacity on the 4th day of conditioning. Water holding capacity is computed as:

$$\text{WHC}\,[\%] = \frac{\text{fresh weight - dry weight [g]}}{\text{dry weight [g]}} \times 100$$ and thus can exceed 100%.

SIR was carried out according to the procedure given by SCHINNER ET AL. (1993) with some modifications: Samples were incubated as fivefold replicates including one unamended control. For each replicate 20g of soil were filled in a fine-mesh nylon bag and placed in an airtight glass jar containing 20ml of 0.1M NaOH. After 4 hours, samples were removed from the jars. Following the Isermeyer approach, CO_2 evolving through respiration is trapped by a known amount of sodium hydroxide and then precipitated with barium chloride (forming $BaCO_3$). CO_2 evolved from the soils was precipitated from the NaOH using 2ml of 0.5M $BaCl_2$. NaOH not consumed by CO_2 was backtitrated with 0.1M HCl adding 3-4 drops of phenolphthalein indicator. CO_2 evolved from respiration can be computed as:

$$\frac{(\text{Blank} - \text{Sample}[\text{ml HCl}])\ \ 2.2\ \ 100\ \ 100}{4\ \ \text{sample weight}[\text{g}]\ \%\text{DM}} = \text{mgCO}_2\,100\text{g}^{-1}\,\text{DM}\,\text{h}^{-1} \ ,$$

which can then be converted into microbial biomass carbon (C_{mic}):

$$20.6\ \text{x}\ 10\ \ \text{mgCO}_2\,100\text{g}^{-1}\,\text{h}^{-1} = \mu\text{gC}_{mic}\,\text{g}^{-1}$$ (SCHINNER ET AL. 1993).

A pretest was first carried out to determine the minimum dosage of glucose required to render a maximum reaction of microbial respiration. Different dosages of 0, 75, 150, 300, 600 and 1000mg glucose per 100g dry soil were tested as well as different concentrations of NaOH and HCl to obtain adequate resolution of titrated values.

35 applied in solid form, not dissolved (see LIN & BROOKES (1999) for discussion).

Soils need to be in equilibrium for SIR; recently fertilised or tilled sites with growing or decreasing microbial populations are not suited for SIR experiments (Anderson & Domsch 1978). This precondition was assessed for Cienda soils in 2004: In a pre-test, respiration had been observed after 1, 2, 3 and 4 hours of incubation to monitor the shape of the respiration curve for horizontality (Schinner et al. 1993). In 2005, interviews with landowners or tenants were used to assure that such changes had not occurred recently.

2.5.16 Basal respiration

As for SIR, basal respiration (BR) of sieved soils, excluding roots and macrofauna, is measured as evolution of CO_2. In contrast, no substrate is added, temperature is not adjusted and incubation periods exceed four hours. BR method is used to reflect microbial metabolism under controlled yet close-to-natural conditions.

In 2004, several pre-tests were carried out: Different concentrations of NaOH and HCl were compared for trapping CO_2 and titration; 0.1M NaOH and 0.1M HCl were identified as best concentrations to trap the entire amount of CO_2 and at the same time allow for sufficient resolution during titration.

Soil was broken up but not sieved; roots were sorted out with forceps. Water contents were adjusted to 50-60% of water holding capacity before the experiment started. During the incubation period of 30 days, water contents were controlled and losses in the airtight jars found to be negligible; thus moisture was not adjusted during the experiment. Transport and storage before the experiment were as for SIR including an incubation period of 5d at room temperature. 30g of field fresh soil were used per sample. The experiment was carried out following the procedure given in Schinner et al. (1993). Each sample was repeated in 7 technical replicates plus one blank (no soil) to evaluate the quality of the method. Samples were incubated at room temperature, transferred to new glass jars after 1, 3, 6, 12, 18, 24 and 30 days and titrated after each transfer. Samples from all subplots were collected, incubated and analysed simultaneously, so that there were no differences with respect to temperature.

During the second year, water contents were adjusted to 55% of WHC to make measurements on different dates more comparable. This was necessary due to a larger number of different plots, which could not be processed parallely anymore. Also, technical replicates were reduced from 7 to 4, which had been found sufficient to prove statistically significant differences between plots. Experiment duration was reduced, too, (changes after 24, 96 and 168h) as longer experiments did not make findings more evident.

2.5.17 Soil respiration

For Cienda subplots 1-13, soil respiration was also estimated in situ following the pail method described by Anderson & Ingram 1993. In contrast to the aforementioned respiration methods, this analysis includes faunal and root respiration over the entire profile depth. As installation of pails disturbs relatively large areas of an experimental field, there were only two replicates installed per subplot to roughly assess if tendencies were comparable to BR analysis.

After removing all aboveground biomass, a glass vial containing 1M NaOH was placed under a pail, which was inserted 3-4cm into the topsoil and the soil compressed against the pail; thus gas exchange of in- and outside atmospheres was minimised. After 24h of exposure, the set-up was opened, glass vials were sealed, removed and brought to the laboratory, where precipitation and titration (here with 1M HCl) were carried out as for basal respiration. Results are presented as g CO_2 cm^{-2} d^{-1}, where

area of the pail – area of vial = $484.15cm^2 – 16.76cm^2 = 467.39cm^2$.

Shortly before the installation, samples for parallel BR analysis had been taken next to the pail positions. Simultaneously to the experiment, soil temperature in 5cm depth was monitored in two subplots (under closed canopy and in an open area) during the exposure period.

2.5.18 Phosphatase activity

Measurements of phosphatase activity are used to assess activity of phosphate-transforming enzymes at soil pH, which includes phosphatases of plant roots as well as such of microorganisms.
In the experiments, accordingly to Schinner et al. (1993), di-sodium phenylphosphate served as a substrate, which is split up by phosphatases into phosphate and phenol, the latter being detected photometrically in relation to phenol standard solutions.
Samples were taken at the same dates as those for BR and SIR. After cooled transport to the laboratory and discarding roots, the field fresh samples were stored in a deep-freezer. Before analysis, soil samples were defreezed and conditioned at room temperature for five days. Each sample was processed as threefold technical replicate with one additional blank. To 5 g of soil, 10ml of 0.2M di-sodium phenylphosphate and 10ml H_2O_{dist} were added into Erlenmeyer flasks, for the blanks another 10ml distilled water were used instead of the substrate.
Incubation of the samples was during 3 hours at 37°C. After incubation samples were immediately transferred to a cooled room, where activated carbon was added. After shaking, samples were filled quantitatively into 50ml volumetric flasks, volumed and filtered through Whatman #42 filter papers. 2ml of the filtrate were then transferred into 100ml volumetric flasks, which had been prepared with 5ml borate buffer solution and 1ml 2,6-Dibromoquinone-Chloroimide as colouring agent. Phenol was determined photometrically at 614nm against phenol standards.
In modification to the procedure described by Schinner et al. (1993), 5ml of 0.2M instead of 0.1M substrate solution were used as a pre-test had shown that the indicated amount of substrate gave very low phenol readings. Further, measurements were conducted with distilled water at soil pH instead of buffer solutions used for acid or alkaline phosphatase. Nevertheless, a borate buffer (pH 10) was added after filtration to make the colourant work (and also for the standards). Incubation was at 37°C for 3 hours, the following steps were then carried out in an air-conditioned room at approximately 22°C to stop the enzymatic processes, which might have gone on at 32°C room temperature. After filtration, flasks were wrapped in aluminium foil to protect the solution from light. To avoid turbidity of extracts (probably due to iron oxides), which interferes with the wavelength to be detected, activated carbon (ground and acid-washed) was used after incubation to clear the solution. Erlenmeyer were used instead of volumetric flasks for incubation and shaking; then the solution was quantitatively transferred into volumetric flasks. Absorbance values obtained from the photometer readings were transformed into µg phenol concentrations per ml. In a second step, phosphatase activity is expressed as µg phenol per soil and incubation time:

$$\frac{(\mathrm{Sample}-\mathrm{Blank}[\mu g/ml])\ \ 50\ \ 100}{\mathrm{Filtrate}[ml]\ \ \mathrm{Weight\,of\,Sample}[g]\ \ \mathrm{Dry\,Matter}[\,]}=\frac{\mathrm{Phenol}[\mu g]}{\mathrm{Dry\,Matter}[g]\ \ 3h},$$

where sample (mean of replicates) and the respective blanks are given as µg phenol / ml, 50 = ml extractant volume, 100 / (% dry matter) = conversion for water contents.
As suggested by Denich & Kanashiro (1998), pH and P_l were parallely determined for every phosphatase sample.

2.6 Biomass measurements

2.6.1 Mulched biomass

Biomass cut during plot preparation in Cienda was estimated from subsamples. Lay-out of the five-by-five meter grid for trees to be planted was carried out the day after brushing. Within every second 25m^2 quadrant (corresponding to all fields of the same colour on a chess board), a 1x1m square was randomly selected by drawing a number. All aboveground biomass within this 1m^2, which had been cut during brushing[36], was collected and necromass discarded. Woody and non-woody parts were separated . Samples were oven-dried at 70°C until constant weight; dry matter was recorded separately for both fractions.

2.6.2 Undergrowth biomass and growth rates

A rough assessment of undergrowth biomass and growth rates as reference for modelling was carried out under canopies of different density. Five squares of 1x1m were laid out under dense, medium and no crown cover, respectively. AGB was cut in February 2006, separated into woody and non-woody parts, oven-dried (70°C for 24h) and weighed. The regrowing AGB was then cut again after 6 and 12 weeks, i.e. at the end of the rainy and during the dry period. Carbon contents of three composite samples were also determined.

2.6.3 Root length and weight density

Soil samples were taken from 0-15 and 15-30cm[37] using an Eijkelkamp soil corer of 15cm tube length and 7cm inner tube diameter. A maximum distance to trees was kept to ensure that RLD reflected stand density. Two replicates per subplot were sampled, but only one, A series, each was lastly analysed for root length density (RLD) due to labour-intensity of the method. The B series was used for a complementing RWD analysis.
Roots were washed out of the soil cores in the lab and separated into live and dead: First by floating in water and then manually sorting out, using colour and elasticity as distinguishing criteria[38]. Roots were then dried for one hour, cut into pieces and scanned. Root length was determined in Hohenheim using WinRhizo 5.0 (Bauhus & Messier 1999) and related to the volume of the soil core to calculate RLD. RWD was calculated for a replicate of every RLD sample, divided into fractions > and < 1.5mm diameter. Additionally RWD of roots >2mm from OM fractions analysis (2.5.14) were taken as reference. Dry matter per soil mass values were multiplied with bulk density obtained from the soil profiles. Bulk density entered as a mixed factor, weighted according to thickness of horizons.

2.6.4 Aboveground biomass growth of planted species

In order to assess performance of the planted trees and abaca in different environments (regarding canopy closure, slope position and soil properties), various measurements were conducted. Six inventories were carried out during the first two years after planting, recording all plant heights and stem diameters. To relate these values to biomass increase, three individuals per species were measured non-destructively in detail for calibration and deduction of empiric allometric equations. Biomass could then be converted into amounts of sequestered carbon. Biomass values were also estimated

36 This refers to herbs, shrubs and small trees only, as medium-sized trees were not cut.
37 These were defined after root counts from the soil profiles.
38 As assignment was not unambiguous in many cases, this aspect was not considered for data evaluation.

using the WaNuLCAS model, which is based on functional branch analysis (FBA) of mature trees. While the 'manual' generation of allometric equations does not allow for extrapolation beyond the calibrated range, this was possible using WaNuLCAS, which requires only partial analysis of grown-up trees to estimate the entire tree biomass.

2.6.4.1 Inventories

With regards to drought being the principal cause for mortality and growth retardation, a first tree inventory (June 27-28, 2004) was undertaken shortly after the dry season that followed planting to account for the established trees and abaca. Further dates were November 11, 2004 and April 14, 2005, both before, and June 29, 2005, shortly after dry season. Two more measurements were carried out in December 2005 and April/May 2006.

Tree height of each plant was measured from ground level to the lower end of the terminal bud. For abaca the bifurcation between the two youngest leaves was chosen as upper point. Instead of conventional diameter at breast height (130cm), diameter was measured at 5cm above ground level. This point was marked with an indelible colour pen and diameter was determined using a calliper gauge. Mortality was also recorded.

In addition, monitoring of leaf damage was conducted five times from the second growth inventory (Nov. 2004) until January 2006. Damages were estimated in percent of leaf area and categorised into pest damage, sunburn and others (mainly black, red and yellow spots). Mechanical breakage of shoots was also denoted.

2.6.4.2 Calibration for allometric equations

As destructive methods were not appropriate, three individual trees per species were gauged in detail for biomass determination. These individuals included the tallest, one of the smallest and one medium exemplar to cover the whole range of planted trees and avoid extrapolations. Length and diameters at both ends of every stem, branch or twig were determined separately. Where segments' cross-sections were oval, two perpendicular diameters were taken and volumes were calculated for cylinders/frustra with elliptical basal areas. For compatibility, the same diameter classes for wood, branch and twig as for the FBA method (see 2.7.2.1) described by Mulia (2001) and Mulia, Purnomosiddhi & Lusiana (2001) were used. Wood is thereby defined as >5cm in diameter, branch 5-2cm and twig <2cm.

Wood, branch and twig density (at 0% moisture) of each species were determined by weighing oven-dry subsamples of known volumes. Displacement of water (with detergent) and geometric calculations were both used to compare precision of volume measurements. Where literature values (ICRAF wood density database at www.worldagroforestrycentre.org, Soerianegara et al. 1993 and FAO 1982) for air-dry wood density complemented own measurements, these were adjusted to 0% moisture neglecting shrinkage. Multiplication of woody volume and density gave then woody aboveground biomass of the respective tree.

Previous leaf measurements had served to establish length – width ratios. For average leaf area, scanned leaves were measured using WinRhizo 5.0 software and then regressions were formulated to estimate area from either leaf length, width or length multiplied by width. As criterion r^2 of regressions was employed.

Specific Leaf Area (SLA) had been determined as average of 10-20 oven-dried leaf circles of known diameter and gave the inverse specific dry weight per unit area. The method has been described by Mulia, Purnomosiddhi & Lusiana (2001).

For the calibration procedure, leaf length of a number of single leaves was measured and an average leaf length was calculated. Given the abovementioned ratios and the number of leaves per tree, leaf dry matter for every species could be estimated. This was added to woody biomass to account for total aboveground biomass (AGB).

2.6.4.3 Allometric equations

Several types of alternative regressions were fitted to predict biomass values from diameter and/or height. In a first step, relationships between stem diameter and height of all trees were tested to decide, whether both parameters or only diameter should be considered for the allometric equations. Generally, including height into the regression equation would add accuracy, but in cases of distorted growth, mechanical damage etc. would lead to greater deviation.
Allometric equations were then fitted on the basis of the calibration measurements described beforehand. Regressions were formed following the exponential shape

$$B = a\, D^b \qquad \text{or} \qquad B = a\, (HD^2)^b$$

where *B* is biomass, *H* height, *D* diameter at 5cm height and *a* and *b* are empirical species-specific values (see Ketterings et al. 2001).

2.6.5 C, N and P contents of plant tissues

Composite samples of each tissue type – leaves, twigs, branches, wood and roots of the ten planted tree species plus *Gmelina arborea* and leaves, pseudostem and roots for abaca - were analysed at SRTPAL Leyte following standard procedures:

2.6.5.1 Plant C analysis

Sample preparation for C and P analysis: 0.5g oven-dry plant tissue is ashed at 550°C in a muffle furnace during 6-8 hours, until the sample turns white (black particles are removed with 3ml of concentrated HNO_3). The ash is then dissolved in 3ml concentrated HCl overnight, quantitatively transferred into a 100ml flask and volumed with 0.1N HCl. After filtering through a Whatman 42 or equivalent filter paper, C and P are analysed.
C analysis was conducted according to the modified Walkley-Black procedure as described under 2.5.13.3 for soils.

2.6.5.2 Plant P analysis

Plant phosphorus is analysed in 1ml ashed tissue sample extract, which is amended with a reagent 'C' composed of two solutions (Stock Solutions A and B as described under 2.5.9). 10ml of reagent 'C' are mixed with the tissue extract and left for 15min before being measured fotometrically (here: Bausch and Lomb Spectronic 20) at 880nm. Standards are made from 0.4394g oven-dried KH_2PO_4 plus 5 drops toluene in 1l H_2O_{dd}. From this 100ppm stock solution, working standards are prepared.

2.6.5.3 Plant N analysis

Plant N was analysed following the SRTPAL standard procedure based on the Kjeldahl method. In the presence of a catalysing mixture (K_2SO_4, cupric sulphate pentahydrate and selenium), organic N is converted to $(NH_4)_2SO_4$ through reaction with H_2SO_4 and then to NH_4OH by addition of NaOH. During the subsequent distillation, NH_3 is set free and bound by H_3BO_3 as $(NH_4)H_2BO_3$. N is then quantified indirectly by titration of $H_2BO_3^-$ with HCl.
To 0.5g of ground air-dry plant sample, 0.2g of selenium catalyst mixture and 3ml of conc.

H_2SO_4 are added. The solution is heated until clear. After digestion, the liquid is allowed to cool and 30ml of distilled water are slowly added after quantitative transfer into a Buchi flask. Distilled NH_3 is collected in an Erlenmeyer flask containing 25ml of 2% H_3BO_3, 3 drops of mixed bromcresol / methyl red indicator and 20ml of 40% NaOH. Titration starts directly after distillation with 0.05N H_2SO_4 as titrant. Parallely to the samples a blank is analysed and the results are computed according to the formula:

$$N\,[\%] = \frac{(H_2SO_{4\ \text{sample}} - H_2SO_{4\ \text{blank}}[\text{ml}])\,N_{\text{titrant}}\,0.014}{\text{sample weight [g]}}100$$

where $N_{titrant}$ stands for normality of the H_2SO_4, and 0.014 is the meq of nitrogen.

2.6.6 Litter production

To assess litter production under different canopy cover in Cienda, litter traps were randomly installed inside the subplots as proposed by ANDERSON & INGRAM (1993). Six litter traps with a surface area of $0.25m^2$ each (50x50cm) were set up per subplot. The collected plant material was segregated into leaves, branches & bark and flowers & fruits, dried at 60°C and weighed. For larger branches and coco leaves, only the part lying on the trap was cut off for weighing.

Traps had first been installed by DIEHL (2005) and litter recollected irregularly. From early 2005 up to the destruction of most traps in February 2006, litter harvesting was carried out monthly. The same experiment was set up in Marcos plots from Feb – May 2006 to compare litter production in reforestation plots with indigenous vs. exotic (*Gmelina arborea*) trees.

2.6.7 Litter decomposition

PVC rods containing 12 minicontainer capsules each (as described by EISENBEIS 2004 and DUNGER & FIEDLER 1997; fig.29) were filled with 0.1500g dry matter of different standard plant materials[39] and inserted horizontally into the soil at a depth of 5cm. Exposition periods varied according to plant materials (2 weeks and 5 weeks). Two different types of nylon nets where used as cover to allow access for specific decomposer groups: 4mm (access for most decomposers) and 0.1mm mesh (to exclude the macro- and mesofauna). Plant material was oven-dried at 70°C for 48h before and after exposure.

The same set-up was used for an experiment in Marcos comparing *Ficus*-dominated substrate as well as plot-specific leaf litter of rainforestation vs. Gmelina plantation during wet and dry season.

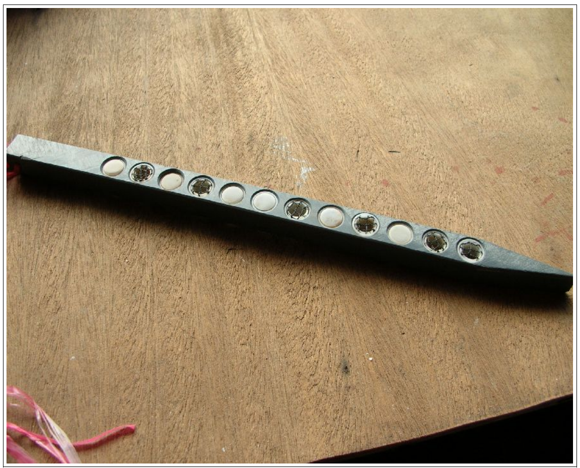

Figure 29: Minicontainers in PVC rod, mesh 4mm and 0.1mm, randomly distributed

39 easily decomposable *Leucosyke capitellata* leaves and *Cocos nucifera* fine roots in a second run

2.7 Plant measurements required for modelling

Numerous models have been formulated to predict soil organic matter in different pools on a plot (CHERTOV & KOMAROV 1996; COLEMAN & JENKINSON 1996; COLEMAN ET AL. 1997; FRANKO 1996, KELLY ET AL. 1997, MOLINA ET AL. 1996; for an overview POWLSON ET AL. 1996) and landscape level (PAUSTIAN ET AL. 1997a; FALLOON ET AL. 1998; V. NOORDWIJK 2002). Among the existing plant growth models, WaNuLCAS was chosen because it is designed explicitly for agroforestry and can simulate interactions and simultaneous growth of up to four plant species in a mixed planting system. The model was written for tropical agroecosystems and parametrisations for some of the trees used here was already available for comparison with own measurements. Relevant modules for this research, especially with regards to the carbon cycle, allow extensive options to feed own data into the model. The model has a user-friendly interface, but the underlying algorithms can be modified on the Stella 'subsurface'. Updated technical support, also with respect to gathering of input data, is facilitated by ICRAF through manuals, publications and procedures. WaNuLCAS is freeware, but requires a commercial environment, Stella. The version used for this study was WaNuLCAS 3.1.

2.7.1 Crop parametrisation

Apart from soil and weather data (on a daily time-step), working with WaNuLCAS requires specific inputs for plant parametrisation. These include a tree survey focussing on habitus, phenology and physiology of the selected species.
Different support programs have been written to derive inputs for crop parametrisation in WaNuLCAS, which are usually not included in standard measurements. These are Light Use Efficiency (LUE), Specific Leaf Area (SLA), Leaf Weight Ratio (LWR), Harvest Allocation and Root Allocation. WOFOST (BOOGARD ET AL. 1998), a software recommended for WaNuLCAS (RAHAYU ET AL., available online) simulates optimum crop growth depending on growth stage; outputs are then entered into a *WanHelp* spread sheet, which delivers input parameters for the crop library in WaNuLCAS. While SLA and LWR data were collected on site, LUE as well as harvest and root allocation were derived from WanHelp, based on dry matter of different plant fractions at various growth stages.

2.7.2 Tree parametrisation

This part of the survey can be addressed through interviews with experienced farmers, extensionists or other resource persons. Other parameters need to be quantified experimentally; these are specific leaf area (SLA), wood density, C, N and P (see previous sections) as well as Functional Branch Analysis, leaf weight ratio, polyphenolics and lignin contents of leaves and fine roots (see below).

2.7.2.1 Functional Branch Analysis and Leaf Weight Ratio

FBA is a method employed to describe branching patterns of trees based on non-destructive measurements. Roots and stems are seen as transport channels for water and dissolved substances and their shape, especially cross sectional area, is determined by magnitudes of these fluxes (V. NOORDWIJK, SPEK & DE WILLIGEN 1994). Assuming a self-repeating pattern of branching from fine roots to proximal roots and then from the stem towards branches and twigs, species-specific geometric ratios can be observed. To come to these ratios, length and diameters of aboveground plant segments or *links* per plant are measured. The first aboveground link would always be the stem from the ground to the origin of its lowest first-order branch; the second segment would then extend from the beginning of the first branch to the first second-order branch turn-off and so on. Length, two diameters (measured perpendicularly to account for elliptical cross sectional area in the middle of the segment), linkage to parent and number of leaves are noted for at least 100 aboveground segments (table 6).

Table 6: Schematic FBA protocol

Link #	Length	Diameter 1	Diameter 2	Parent #	Number of leaves
1 : 100 +x	: : :	: : :	: : :	: : :	: : :

These data are copied into WanFBA, a pre-processing software for WaNuLCAS, where inputs are checked for plausibility. Factors *p* and *q* and their respective means and ranges are the most important variables dominating the branching pattern. The first describes the squared diameter (representing cross sectional area) of a parent link in relation to that of all of its daughters

$$p = \frac{D^2_{parent}}{\sum D^2_{daughters}}$$

and q the ratio of the thickest daughters' squared diameter in relation to the sum of all its sisters' squared diameter:

$$q = \frac{D^2_{max}}{\sum D^2_{daughters}}$$

As the branching pattern is fractal, a user-defined minimum diameter *Dmin* needs to be set to stop the downscaling process; *Dmin* may be chosen < *Dlow*, the smallest measured diameter on a twig. Bare Tip Length (from the junction of the youngest leaf to the tip) and Leaf Weight Ratio (LWR), describing dry weight of leaves relative to leaves + woody parts, are further inputs for the parametrisation. These data are usually collected in the process of FBA for the same branches.

WaNuLCAS will then fit allometric regressions for each individual based on the processed exports from WanFBA.

Averages of three mature individuals of S*. contorta*, *G. arborea*, *A. heterophyllus*, *A. odoratissimus*, *D. zibethinus*, *N. lappaceum*, *G. mangostana* and two replicates for *D. validus* were used for allometric equations derived from FBA. While the procedure demands a minimum of 50-100, at least 100 links were measured per plant. If exceeding 100 links, the entire branch, at times >200 links, was included.

For roots, generally the same procedure is applied, starting from the proximal root and denoting number of fine roots instead of leaves. Additionally, average length of fine roots and length per dry weight are determined. Especially in heavy soils roots are not easily accessible without breakage. In consequence the method is labour- and time-intensive, so that for this study less segments were measured per plant and not all species could be sampled. Alternatively, WaNuLCAS offers two more options to estimate roots biomass, one being maximum root length density per zone, which were obtained for some cases

following the method described under 2.6.3.
All other procedures mentioned in this section were described by MULIA (2001) and MULIA, PURNOMOSIDDHI & LUSIANA (2001) and are available online[40].

2.7.2.2 Total extractable polyphenol (Folin – Ciocalteau method) and lignin contents

0.2g of ground plant sample are placed in a 50ml beaker and 20ml extractant (50% methanol dissolved in distilled water) is added. The beaker is covered with a watch glass and heated in a water bath at 75ºC for one hour. The extract is filtered (filter paper #1) and volumed to 50ml with extractant. 1ml filtrate is transferred into a 100ml volumetric flask and 60ml distilled water, 5ml Folin-Ciocalteau reagent and 15ml of 20% sodium carbonate solution are added before voluming to 100ml with distilled water.
Standards are prepared from a 1mg ml^{-1} tannic acid stock solution. 0, 1, 2, 3, 4, 5, and 6ml of stock solution are pipetted into 50ml volumetric flasks; 2.5 ml of Folin – Ciocalteau reagent and 10 ml of 17% sodium carbonate are added before voluming with distilled water.
Absorbance of standards and samples is read at 760 nm using a spectrometer and expressed as tannic acid equivalent (TAE).
Total Extractable Polyphenol is computed as follows:

$$TEP[\%]=\frac{(TAE_{sample}-TAE_{blank}[mg])\ 50}{10\ \ sample\ \ weight\ [g]}$$

2.8 Statistics

Statistical evaluation was carried out with SAS 8.2, Minitab 13 and SPSS 12.0. Averages, standard deviations, coefficients of variance, coefficient of determination and correlations were calculated in OpenOffice Calc 1.1.5 spread sheets.
For statistical evaluation of model goodness of fit, the following parameters as suggested by LOAGUE & GREEN (1991) were employed:

Coefficient of determination:

$$CD=\frac{\sum_{i=1}^{n}(o_i-\bar{o})^2}{\sum_{i=1}^{n}(p_i-\bar{o})^2}$$

Root mean squared error:

$$RMSE=[\sum_{i=1}^{n}(p_i-\bar{o})^2/n]^{0.5}\frac{100}{\bar{o}}$$

Modelling efficiency:

$$EF=\frac{[\sum_{i=1}^{n}(o_i-\bar{o})^2-\sum_{i=1}^{n}(p_i-o_i)^2]}{\sum_{i=1}^{n}(o_i-\bar{o})^2}$$

,where o_i are observed and p_i predicted values; overlined o stands for the mean of observed values and n for the number of observations.

40 At www.worldagroforestrycentre.org