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Annex 5

Case study
Agroforestry systems

Final Report
Agricultural Technologies for Developing Countries

STOA Project "Agricultural Technologies for Developing Countries"

April 2009

European Technology Assessment Group
- Institute for Technology Assessment and Systems Analysis (ITAS), Karlsruhe
- Danish Board of Technology (DBT), Copenhagen
- Flemish Institute for Science and Technology Assessment (viWTA), Brussels
- Parliamentary Office of Science and Technology (POST), London
- Rathenau Institute, The Hague

Agroforestry –
an agricultural technology for developing countries

Contribution to the STOA project

(European Technology Assessment Group,
EU Framework Contract No. IP/A/STOA/FWC/2005-28)

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January 2009

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Stuttgart-Hohenheim, January 2009

Cover fotos: Left: Cabbage, strawberry, citrus system. Right: Diversified multi-storey clove-based system with papaya, coffee, fodder grasses, banana, cassava, maize and ornamentals. Both sites are situated near Seririt, Bali, Indonesia. All agroforestry fotos by C. Marohn unless stated otherwise.

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1 Summary

In this study, agroforestry systems *sensu strictu* are defined as land uses, which simultaneously combine deliberately interplanted annual crops and trees. These systems can be highly diverse in species composition and physical structure. Agroforestry design integrates and imitates generic principles and functions of natural ecosystems and adapts them to local conditions. Thus, agroforestry offers a great potential for sustainability, although it has some limitations and constraints.

The effective and efficient use of the natural resources available is commonly perceived as an important key to sustainability. In agroforestry design, this is achieved by complementary structuring of annual and perennial plants in different storeys. In doing so, a variety of ecological niches can be productively explored whereas inter- and intraspecific competition are ideally minimized. An appropriate set-up requires to consider the specific demand for light, water and nutrients of each component in their successional, seasonal and spatial variability. Another key principle applied is the establishment and maintenance of a tight nutrient cycle. This includes the nutrient fixation through leguminous trees, the safety net function of deep-rooting trees against the loss of nutrients as well as the nutrient pump function, i.e. circulation of minerals from deeper soil horizons through roots and leaf litter onto the soil surface, where these nutrients are available to shallow-rooting plants.

Additional beneficial effects result from the physical water retention function (reduction of direct run-off and evaporation) through a permanent vegetation cover, increased leaf litter, humus and improved soil structure. Multi-strata canopies can contribute to a significant reduction of microclimatic extremes and ensure an extended availability of soil water. This in return favours vegetation, root penetration as well as a perpetual microbial colonization with positive feedback effects on the nutrient cycle. In fact, comparative studies prove that agroforestry systems in terms of water use efficiency can be significantly superior to monocropping systems.

Accumulation of soil organic matter (SOM) and the maintenance of a high soil humus content is another core element of sustainable land use represented in agroforestry. A high soil humus content both stabilizes the soil structure against erosion and stores nutrients. Quality and quantity of SOM depend on species composition, their biomass production and input through litter, human activities such as pruning, mulching or manuring, but also on decomposition rates. In agroforestry the annual and perennial components of vegetation can provide both the permanent source of SOM and the protective function against wind and water erosion, a function that may be enhanced by appropriate management practices, such as terracing or hedgerows.

In ecology the principle of succession describes the colonisation of ecosystems through time. Natural succession is characterised by increasing biomass and diversity at decreasing growth rates. While monocropping systems rather resemble pioneering stages of vegetation in open areas, agroforestry imitates complex successional stages of natural ecosystems in rather advanced stages. A high biodiversity is hence a distinct feature of such systems. Although species composition is often altered intentionally and diversity levels mostly remain below those of natural forests, the habitat quality of agroforestry systems in general remains high. The purposeful structural and organismic diversification – a mixture of crops and 'unprofitable' plants - on the other hand increases the systems' self-regulation capacities and thus their overall resilience against pests, diseases and abiotic stress.

To the same extent this diversification minimizes economic risks for farmers in case of crop failure, decaying market prices or consumer demand.

With the increasing influence of globalised markets on smallholders' incomes and livelihoods, a diversified portfolio of annual crops and perennials, in particular trees, does not only create a certain resilience against market failures, but also increases self-sufficiency and options for self-supply with a variety of healthy food (i.e. fruits), timber, fodder, fuel wood or medicinal plants.

In summary, agroforestry systems provide a variety of set-ups modelled on successional stages of forests with the purpose of minimizing costs and inputs, maximizing productive functions and self-sustenance while maintaining and enhancing essential environmental services.

There are countless agroforestry systems that have been developed across the globe. Primarily they can be classified according to their main managed components into

1. Agrosilvicultural systems: Annual crops and shrubs / trees;

2. Silvopastoral systems: Pasture or cut fodder with animals and trees;

3. Agrosilvopastoral systems: Trees, crops, pasture / cut fodder and animals.

In a second step the systems can be differentiated according to their spatio-temporal arrangements, functions and organizational aspects. Finally land use intensity or management can be used as additional classification criterion.

Extensive systems, such as semi-nomadic types of forest clearings or selective planting along frequently used trails, have been applied since millennia. These traditional practices still today serve as models for near-natural, sustainable land use and can be considered as vital and primary source of nowadays' knowledge on agroforestry.

Among the sequential and semi-simultaneous systems, *taungya* (interplanting of cash or food crops with forest seedlings in the early stage of reforestation schemes) is considered as progenitor of modern agroforestry.

Especially in tropical areas, where increased human pressure requires to curtail the fallow period for soil regeneration, *improved fallows* with leguminous nitrogen fixing perennials are established as further development of traditional shifting cultivation. Soil recovery is mainly enhanced by the use of the multi-purpose woody leguminous species or the strategic use of fertilizers.

In spatially differentiated agroforestry *hedgerow planting* is widely used. Though the hedges planted along contour lines provide multiple benefits (soil protection, fodder, fuel wood) farmers may refrain from establishing such systems due to the potential competition with the annual crops in terms of nutrients, water, light and space. *Windbreaks* and *shelter belts* along coastlines and riverbanks perform similarly, however partly without annual components.

Among the animal-based systems only a few silvopastoral systems may be considered as agroforestry in a broader sense. Hereunto counts keeping livestock under fruit trees for fertilizing, repressing grass and competing undergrowth and for easing the gathering of fruits. In agrosilvopastoral systems annual crops, perennials and livestock are combined in various sequential (e.g. *livestock-under-tree* following a *taunyga* system) or spatially differentiated set-ups (e.g. feed-damage protection through living fences).

Contrasting the afore-discussed systems, intensive agroforestry is mostly characterized by higher biotic and structural diversity, which in return requires farmers' increased attention and management. *Homegardens* represent a prominent, wide-spread land-use system in many tropical regions. Their assemblages of multipurpose trees and shrubs with annual and perennial crops and various livestock, located within the compound, provide a variety of economic, ecological and social functions and values including food self-sufficiency, recreation or spiritual retreat.

Contrasting to home gardens, *multi-storey tree gardens*, usually located at some distance to the homestead, may spare the annual component. The system combines various multi-purpose trees and perennials in a forest-like system with at least two storeys.

For potentially smallholder-dominated commodity crops like rubber, banana, cacao or coffee, integrated cropping systems or cultivation in low intensity managed forests represents a viable setting. These can pose an alternative to large-scale high input estates, if recollection and marketing are assured.

Successional agroforestry mimics natural transcourse of vegetative colonization most closely, arguing that climax vegetation is best adapted to environmental conditions on site. This means that the crops and species used at a given time correspond with the plant communities of the respective successional stage, e.g. pioneers, early and late successional guilds. Archaic Philippine Hanunóo systems, *rainforestation*, South American s*istemas multi estrato* (multi strata systems) or Sri Lankan a*nalog forestry* are examples of natural succession accelerated by human intervention (e.g. synchronized plantings, pruning, weeding). Depending on the design strategy (ecotourism, carbon sequestration, agricultural crops etc.), exotic species along with the keystone native species are introduced under the condition of being analogous to the natural vegetation in structure and ecological function.

Agroforestry systems require in-depth knowledge and extended practical know-how and experience on plant characteristics, uses and compatibility. Although the principles may be generic, care needs to be taken in transferring exact copies of one practise to different environments: The success of agroforestry practices is strongly interrelated with the evolution and tradition of local knowledge; on the other hand, integration of local knowledge foments acceptance, ownership and thus the potential for sustainability. Adapted systems can represent an integral element of a viable socio-economic system in its specific cultural environment. Hence, agroforestry systems can disprove the perception of traditional practices and knowledge being backward and underdeveloped. This prejudice is to a certain degree attributable to the fact that agroforestry is a low-input land use practised by mostly poor smallholders – a rather unattractive market for industries and easy to be discredited.

Notwithstanding, advanced scientific knowledge and modern technologies can vitally contribute to enhance the spread and adoption of suitable agroforestry practices, by providing spatial information, improving the knowledge and data base for land use planning, site and impact assessment, modelling, scenario analysis, participatory approaches, marketing and profitability studies.

Beyond the fact that most agroforestry systems are at least partially subsistence-oriented, economic viability as part of sustainability deserves careful attention, in particular because the options for profit generation are important drivers of development in rural areas.

Compared to conventional agriculture labour is a distinguishing input factor of agroforestry. Being primarily a smallholder land use system with a high degree of autarky, labour peaks mainly occur in the initial time after establishment before the canopy closes and trees can outcompete weeds. On the other hand, inputs for maintenance later on require low input of labour force. As agroforestry systems are even observed in densely populated areas such as Java, the land size available is usually not a limitation for the occurrence of agroforestry systems but a determinant for their design.

As mentioned afore, diverse agroforests - along with staple food, fruits - provide farmers with cash income opportunities through a wide range of repeatedly or sequentially marketable products such as resins, fire wood, fruits, animal fodder, medicinal plants, timber and animal products.

In the initial period after establishment, negative cash-flow is a common phenomenon. Consequently, small farmers, usually short in income, rather give preference to those systems that require low financial investment for establishment while providing short-term positive cashflow.

Various case studies illustrate that, in the long run, agroforestry systems often prove to be superior to conventional systems in terms of common economic indicators (e.g. Net Present Value, Benefit-Cost-Ratio). However, these examples can hardly be generalised without taking into account the local settings like site, design, varietiesor socio-economic settings.

As stated earlier agroforests can be considered as appropriate setting for self-sufficiency. This also implies their ability to mitigate economical and ecological risks, which can be strongly interrelated. This quality is gaining increasing relevance in the context of climate change.

On a macroeconomic level agroforestry products account for a significant share (up to 50%) of agricultural exports earnings in many developing economies. On a global scale, potential of agroforestry to provide environmental services recently adds a new dimension, which goes beyond conventional economic criteria and approaches: The internalisation of environmental services like biodiversity and management of genetic diversity, soil and watershed conservation, carbon sequestration, among others could, if monetized, potentially add significant value to these systems and create local economic benefits for development.

In the context of Clean Development Mechnism (CDM) measures, agroforestry can be interpreted as afforestation and reforestation (A&R) and therefore qualifies for carbon credit schemes. Considered as a long term investment (>20 years) positive returns can be expected, which add on the existing productive performance.

Although agroforestry has the potential to participate in CDM, it has been largely neglected at least in terms of credit schemes. In this context it must be considered that this form of land-use is largely smallholder-dominated. Existing regulations, management and monitoring requirements, high transaction costs, lack of credit and start-up funds as well as tenurial issues impose serious barriers to small farmers to access these schemes and markets.

Perceiving agroforestry not only as land use but as a variety of diverse ecosystems that provide market and non-market goods, the Total Economic Value (TEV) is a prominent framework to identify and quantify direct and indirect use values as well as option- and non-use values of ecosystem services which contribute to human well being. Especially non-markets value assessments have extensively been carried out for forest ecosystems, whereas TEV-assessments for agroforestry are scarce. The few case studies available indicate high performance of non-use and indirect use values and better TEV-performances of low-intensity land-uses or agroforestry as compared to deforestation scenarios.

Due to differing perceptions on how to define and discriminate agroforestry systems from forest and other land uses, data on the spatial coverage is sparse and varies to a large extent depending on the source. In 1996 the worldwide area in agroforestry was estimated at 400mn ha. Other estimates show a remarkable potential for expanding agroforestry systems both to degraded and deforested land, particularly on the fringes of tropical forests. This also includes areas currently being legally or illegally deforested. It is estimated that under enabling policies, more than 10mn ha could be converted to agroforests annually.

In general the distribution of agroforestry systems can be clustered into three agroecological zones, namely

- Humid lowlands with shifting cultivation, taungya, plantation-crop combinations, intercropping systems and multi-strata tree gardens;
- semiarid lowlands with silvopastoral systems, windbreaks and shelterbelts, multi-purpose trees for fuel / fodder and multi-purpose trees on farmlands and
- highlands with soil conservation hedges, silvopastoral combinations and plantation-crop combinations.

In Sub-Saharan Africa, tree based agricultural systems could potentially cover an area of almost 1bn ha (> 40% of the land area). Currently only 9 % of this potential has been realised. Tree crops for export, in particular cocoa and coffee, play a dominant role, but tree fruit exports have distinctly increased in the past decades. Africa is particularly struck by HIV/AIDS, climate change as well as population growth, coupled with proceeding deforestation and land degradation. Agroforestry to a certain extent could thwart these problems, but development and spreading of tree crop systems is impeded by lacking inputs, poor market access and market price fluctuations. Various strategies, such as diversification, improved planting materials, post-harvest technologies, credit schemes and the promotion of farmer associations have been recommended to tackle these challenges.

In South-Asia tree based systems are established on 112mn ha but could be potentially doubled. These systems play a major role in semi-arid parts of the Indian subcontinent but can be found dispersed all over the region. The main challenge agriculture (including agroforestry) in general faces is water management, which shall be tackled with diversification strategies.

In the East Asia-Pacific region (including China and Mongolia) the potential for tree based systems is estimated at more than 1.1bn ha with around 14% of the area being currently under such type of land use. In China agroforestry has a long tradition and plays a major role in the context of reduction of wind erosion. Large shelter belt schemes cover more than 11mn ha in the northern and central regions. In other parts of the country different systems of intercropping agricultural crops with trees or so called farmland-forest-networks are very popular and add up to another 15.5mn ha. Recently, rubber plantations are increasing in some regions of Asia such as in Southern China and Vietnam. While smallholder jungle rubber on peat soils in Sumatra is considered a system relatively close to nature, the sustainability of large scale plantations or extension on wide areas is controversially discussed. Although rubber plantations are counted as agroforestry systems by some, they do not fulfil the criteria defined above and are rather opposed to the approach on diversified resilient systems.

For Latin-America and the Caribbean, estimations indicate a potential of some 1.2bn ha of tree-based systems extending over a very wide range of agro-ecological zones with less than 9% of the potential area currently cultivated in such forms. This entails a large spectrum of problem areas but also potentials. It is thus not surprising that a wide range of management and development strategies is offered by the key actors.

In consideration of its great potential but also a number of serious constraints and threats, there is a number of national and international actors dealing with agroforestry in terms of research and development. However, only few institutions on international level have a special focus on this sector, which somehow reflects its negligence in the past. The World Agroforestry Centre (ICRAF) is entitled the world mandate for agroforestry by CGIAR, but also Bioversity International, the FAO and the International Centre for Tropical Agriculture (CIAT) dedicate a number of programs and projects to agroforestry-related issues. Apart from these international agencies there are many national and regional R&D institutions in developing countries as well as university institutes worldwide focusing on agroforestry, not to forget innumerable NGOs.

Research in agroforestry still focuses on the biophysical aspects of such systems, only recently socio-economic issues are discussed on a broader scale. As land use and land use change has become a major topic for research, so has computer modelling, which allows to run scenarios and assess their implications efficiently. Several models for agroforestry exist, that range from inter-species competition on a plot level to environmental functions in the landscape. On the socio-economic side the bulk of publications is on cost – benefit calculations, considering subsistence as well as cash crops and non-market benefits. Neglected fields are tenure and gender related issues.

The great variety of agro-ecological zones, political and social settings does not allow a general ranking of constraints that have to be overcome in order to better tap the potentials of agroforestry. However some of the major obstacles shall be mentioned hereinafter.

If their generic principles are carefully customized, agroforestry systems are flexible and highly adaptable to biophysically limiting factors such as water, light and nutrients, as well as to changing climate conditions. This relates in particular to the structural and biotic design, such as adequate spacing, vertical structuring and proper species-site matching.

Regarding the financial resources required, agroforestry systems can, due to optimized resource use, be more easily adapted to the low input conditions prevailing in many developing countries and small farmer communities. Quality and high yielding planting material is sometimes declared a limiting factor, especially if food-security or improving market supply is an issue. Yet genetic erosion through spread of clones, improved cultivars or genetically modified organisms imposes a serious threat to agrobiodiversity and may imply risks.

In terms of labour demand peaks of labour occur especially in the phase of establishment, but later on natural self-regulation capacities, modern work saving techniques, staggered maturity periods and the longevity of the use system as such allow to keep labour input at a reasonable level.

Insecure or illegal legal land tenure is a basic problem of many developing countries. It does not only obstruct rural development but often abets forest encroachment and land degradation. It acts a disincentive to investment and sustainable land use, especially for tree based systems, which require a secure long-term perspective. A number of studies further suggest that land use practice established also depends on plot size and biophysical characteristics.

Apart from its relevance for self-sustenance, agroforestry has the potential to supply markets with a variety of food and non-food products thereby creating income for farmers. In view of the expansion potential of tree-based systems, provision of market information to assess demand and supply chains, modern processing and storage technologies including, as well as physical market access (roads, transportation) are essential elements for the strategic planning prior to the implementation of a land use system. Their absence in many rural areas is a major bottleneck for development, which adds to a widespread lack of organizational structures, credits and business skills.

The peculiarities of agroforestry predetermine its products for niche markets with price premiums, which in return commonly requires compliance with international standards. To take these chances and gain access to premium markets does not only presume producers' conviction and advanced skills, but also demands to overcome organizational challenges and to master high transaction costs.

Due to the weak delineation against forestry and agriculture, policies and governance are often little conducive to the further development of agroforestry. Legal uncertainties in terms of land tenure rights as well as of administrative sovereignty, over-regulation, bureaucracy or arbitrariness can be identified as major shortcomings. Another limiting factor is that agroforestry due to its internediary position between land use systems may fall between categories eligible for funding.

Last but not least, knowledge and information are a key condiment to the adoption of agroforestry practices and to creating collective and individual ownership and benefits. This implies to consider the local settings, integrate local and traditional knowledge and to provide extension and long term supervision. In this context special attention must be given to disadvantaged groups.

National and international key actors have identified most of the constraints compiled here as focal areas for future research and action which reflect their mid and long term strategies. The related programs mainly address the implementation of gene banks, increased productivity, marketing, mitigation of and adaptation to climate change as well as payments for environmental services.

2 Rationale

This contribution on agroforestry systems forms part of the case studies within innovative agricultural technologies elaborated within the STOA Project *Agricultural Technologies for Developing Countries*. The project elucidates potential contributions of several technologies to higher food production and food security with a focus on small-scale farmers and farming systems.

3 Characterisation of the technology

A definition of agroforestry, its key principles and characteristics are presented in this section to allow conclusions on conditions, potentials, comparative (dis)advantages and constraints of agroforestry systems for development efforts. A selection of relevant types of agroforestry will also be presented to give an overview on options.

3.1 Definition

Many definitions of agroforestry have been proposed (NAIR 1989, ICRAF 1993, LEAKEY 1996), which have in common that agroforestry involves combinations of crops and trees on the same plot. The main distinctions concern simultaneity and use of annual crops.

In this study, agroforestry systems *sensu strictu* are understood as land use systems which simultaneously combine deliberately interplanted annual crops and trees. We additionally present combinations planted subsequently, where the perennial component has been conceived from the beginning as an integral part of the system[1]. Further, systems are discussed that contain only non-tree perennial components such as shrubs.

In addition to this biophysical common denominator, agroforestry is often linked to projections of sustainability and smallholder agriculture. While agroforestry undoubtedly has this potential, it is not seen as a criterion for exclusion for the purpose of this study. As an example, the World Agroforestry Centre provides the following definition: '*Agroforestry is a dynamic, ecologically based, natural resources management system that, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels'* (ICRAF 1998).

Narrowing this definition spatially, this study considers only farming systems, not whole landscapes, interplanting annuals and perennials.

3.2 Key principles, elements and functions

Agroforestry consists of a set of reasoning and design principles rather than fixed planting schemes. Explaining the principles permits to deduct potentials and constraints, opportunities and threats in later sections.

3.2.1 Complementarity and competition

A combination of plant species with complementary habitus can exploit resources in a given ecosystem more effectively than pure stands that compete for light in the same canopy stratum and for nutrients and water in the same soil layer. As in the climax stage[2] of a natural forest ecosystem, multi-storey systems occupy all available niches and resources can be used most effectively. Optimising use of natural resources is particularly relevant in developing countries, where fertiliser prices are often prohibitive.

One central biophysical assumption for the implementation of agroforestry systems is that trees are able to acquire resources of light, water and nutrients that crops alone

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[1] This includes taungya and successional systems, but not extensive rotations of forests, jungle rubber or enrichment planting / fajas de enriquecimiento with negligible annual component.

[2] For details on natural succession, pioneers or climax vegetation see section 4.5.2

would otherwise not be able to acquire (CANNELL ET AL.1996). The so-called nutrient pump refers to this hypothesis: Nutrients restricted to deeper soil layers can be reached by deep rooting trees, mobilised, taken up into the root and allocated to the different plant organs. A considerable share of these minerals is later released from the tree via litter fall (leaves, roots and branches) or washed out by rain (leaves) and deposited on the soil surface, where shallow-rooting plants like associated annual crops can make use of them. This phenomenon is widely known and particularly relevant for plant available phosphorus, which is deficient in many tropical soils, but found in higher concentrations in some subsoils (MAROHN 2007). A related mechanism, the safety net function of trees, applies for mobile ions, which are prone to leaching. Tree roots can form a dense network that prevents these ions from being washed out into deeper soil layers or carried downhill by lateral water flow, where they are not available to plants anymore (CADISCH ET AL. 2004; SCHROTH ET AL. 2001).

Additional inputs of nitrogen can be supplied to agroforestry systems through interplanting with leguminous trees and shrubs like *Leucaena leucocephala, Gliricidia sepium, Cajanus cajan* and others, which in association with bacteria are able to fix N_2 from the atmosphere (KHO 2007). As pioneers in natural ecosystems, the ecological function of these species is to colonise hostile environments and leave them prepared for following species. Figure 1 shows Gliricidia sp. and other (partly planted) leguminous shrubs growing on rocky shallow soil in a strongly water limited environment in Indonesia. These pioneers are not exigent regarding nutrients, water and maintenance; they are usually easy to propagate by cuttings or seed and fast-growing.

Figure 1: Legume shrubs on stony soil in water limited environment in Amed, Bali, Indonesia.

In contrast, it is obvious that fast growing and demanding species act as competitors for sometimes scarce resources. A balanced and effective system design needs to consider demand for light, water and nutrients of each component in their successional / seasonal and spatial variability. In order to understand such complex interactions simulations using computer models are carried out (e.g. maize, cocoa, gliricidia in Sulawesi using WaNuLCAS; SMILEY 2006).

In consequence, an appropriate agroforestry design maintains tight nutrient cycles, maximising resource mobilisation and redistribution. High biomass production, even though not in all parts harvestable, can act as a savings account for the farmer during ‘fat years’. Reduced yields can pay off in the form of soil rehabilitation, improved water retention or other environmental services. Proper design includes the best weighting of productive and protective functions. It will provide a balanced optimum of yields and environmental services following the principles of 'minimizing competition for light and space, water and nutrients maximizing complementary and supplementary effects and creating favourable conditions for growth in such a way that the system provides a greater yield than any of its components in pure stand' (RAI & HANDA, NOT DATED).

3.2.2 Microclimate and water use efficiency

Reduced microclimatic extremes under permanently a closed canopy and maintained soil moisture favour growing conditions for shade-tolerant understorey and late-successional plants. In addition rooted soil and continuous supply with litter can improve soil structure. As an integrated indicator of stable soil moisture, structure and substrate supply, enhanced soil microbial biomass and biological activity has been found under such conditions (YAN ET AL. 2003; MAO ET AL. 1992; MARTIUS ET AL. 2004).

Agroforestry has the potential for improving water use efficiency by reducing the unproductive components of the water balance, i.e. run-off, soil evaporation and drainage. Such effects are provided by the physical retention functions of vegetation cover and structure, litter, humus and soil. Besides improved soil structure, ONG ET AL. (2002) found that simultaneous agroforestry systems in India and Kenya were able to ‘*double rainfall utilisation compared to annual cropping systems, largely due to temporal complementarity’*.

In order to reduce competition for water, lateral root pruning of the tree component has been suggested to force tree roots to expand vertically; however, this measure is limited to plots where groundwater resources can be tapped (ONG ET AL. 2002) and labour availability and costs are not restricting. In practice, pruning and mulching aboveground parts of the perennial component to reduce interception, transpiration, and soil evaporation will be preferred by most agroforesters to balance temporal water shortcomings as it is less labour-intensive and does not require special tools.

In summary, agroforestry aims to minimize water and nutrient losses through permanent soil cover and improved soil structure. As for natural ecosystems, permanent shortage in water and / or nutrient supply will necessarily lead to wider plant(ing) distances.

3.2.3 Soil conservation and soil organic matter management

Degraded and marginal soils are limiting to plant production in many parts of the tropics. Degradation goes hand in hand with reduction of soil organic matter (SOM), which stores nutrients and retains water in the soil. Reasons for diminishing SOM reserves have been widely discussed and include clear cutting, overgrazing or shortened fallow periods (e.g. due to population pressure). As decomposition of SOM is rapid under humid tropical climate, it is crucial for most tropical agroecosystems to maintain or increase SOM contents[3]. Humus accumulation in agriculturally valuable soils is another important part of the farmer’s natural savings account.

[3] SOM accumulation also takes place in anaerobic, dry, acidic or alumic soils, where microorganisms do not encounter appropriate conditions to decompose litter.

SOM management includes increasing inputs and minimising losses. The first can be achieved by litter fall from high biomass, pruning and mulching, as described. Within the second category most relevance has been attributed to a permanent soil cover, reducing especially water erosion. Generally, most measures applied to reduce soil erosion, like minimum tillage, barriers, mulching, terracing, ditches etc. (LINIGER ET AL. 2002; AGROFORESTRY AND MULTIPURPOSE TREES AND SHRUBS R&D TEAM 2003), can be applied in agroforestry systems, too. Soil conservation measures typical and more specific for agroforestry are reduced raindrop impact and splash erosion through permanent soil cover, mulching and multi storey canopies, improved soil structure and infiltration as well as aggregate stability through humus accumulation, and hedgerows as live barriers and most prominent example (see section 4.3). Hedgerow techniques have proved to be effective against water erosion (MERCADO ET AL. 1999, MERCADO ET AL. 2005, BERTOMEU & GIMÉNEZ 2006), but in practice are often not adopted by farmers, mainly for reasons of labour-intensity, space occupied that could be used for crops or competition for resources (PANSAK ET AL. 2008). It is recommended to use multi-purpose or high value species as hedgerows, which justify the effort undertaken or opportunity costs spent (ONG ET AL. 2002). Similar to hedgerows, wind breaks and shelter belts are established to halt wind erosion. As for hedgerows a variety of appropriate species has been identified by practitioners. In both cases spatial arrangement matters: While contour lines are preferred in case of water erosion, straight lines in certain angles to the main wind direction are often used to reduce wind erosion (LINIGER ET AL. 2002).

The ultimate objective of soil conservation in agroforestry as well as any agricultural system is to maintain the soil's ability to support plant growth for crop production purposes and to enable it to sustain high yields. Comparative advantage of agroforestry systems and associated techniques of SOM management is their ability to provide a slowly and continuously flowing source of nutrients and to stabilize or increase the pool of soil organic matter.

3.2.4 Diversity and diversification

Agrobiodiversity refers to the number and composition of species cultivated and tolerated in crop, domestic livestock and aquatic systems. It is a sub-set of general biodiversity, which includes all species of a confined system or area. Ecologically, pure stands of annual crops resemble pioneer stages of succession in a natural ecosystem: They require open areas, are fast growing and dominated by few species, often grasses or leguminous species. Especially successional agroforestry systems (examples see section 4.5.2) are agroecosystems that mimic advanced stages of natural succession such as secondary forest: They are characterised by comparatively high standing biomass, less annual net growth and higher biodiversity (EWEL 1999). Diversification is intended in many agroforestry systems as a strategy of risk minimisation against crop failure and market-related imponderabilities. High agrobiodiversity has been reported from numerous multi-cropping agroforestry systems (THRUPP 1998) like home gardens, fruit groves and cultural forest gardens in the Amazon (SCHMIDT 2003), coconut-food crop systems in Melanesia (LAMANDA ET AL. 2007) or generally spoken in multi-strata systems.

3.2.4.1 Biodiversity and system resilience

Numerous studies give evidence that diversity within indicator groups of organisms decreases with the intensification of land use in tropical forest climax ecosystems[4]. For example, in several agricultural and forest habitat types sampled in Chiapas, Mexico, bird diversity was highest in forest, closely followed by shaded coffee agroforests. Other habitats sampled, such as cattle pastures, multigrain fields, arboreal pastures, and pine savannas, gave home to by far fewer species (GREENBERG ET AL. 1997). In Costa Rica, ant and beetle diversity across three different coffee cultivation types decreased significantly from traditional agroforests through an intermediate type to 0 species in an unshaded plantation (PERFECTO ET AL. 1997).

Factors that are known to foster biodiversity generally include high structural (habitat) and alimentary diversity, including any species necessary for reproduction or food, and a variety of microclimates and microhabitats to support diverse life forms and species (BICHIER 2006). Multistorey agroforestry systems as well as homegardens have been found to contain high species richness, similar to natural vegetation in advanced successional stages such as secondary forests (KRAUSOVA ET AL. 2008).

However, a recent literature review (SCALES & MARDSEN 2008) reveals that 79% of 43 studies on species diversity across forest and agroforestry habitats report reduced diversities in agroforests as compared to neighbouring forests. Recapitulating the study concludes that the *variability in biodiversity retention across systems has been linked most strongly to economic function, management intensity and extent of remnant forest within the landscape, as well as more subtle cultural influences. Species richness and abundance generally decrease with increasing prevalence of crop species, more intensive management, decreasing stratum richness and shortening of cultivation cycles. Knowledge of the general effects of small-scale agroforestry on biodiversity is substantial, but the great diversity of systems and species responses mean that it is difficult to accurately predict biodiversity losses and gains at a local level.*

Diversification in plant species as a strategy to increase structural and organismic diversity can increase the resilience of a system. It is expected that self-regulation of the system can to some extent control pest populations as natural antagonists will balance mass reproduction of noxious organisms (SCHROTH ET AL. 2001). However, building on population dynamics implies a concept of pest management rather than pest control[5]. Although pests may not be combated as effectively as when using pesticides, this approach is preferable for low-input systems (no capital for pesticides) or organic agriculture. It is assumed that even total failure of one crop can to some extent be compensated by income from the other system components. While it may be discussed, whether this low risk strategy is applicable for commercial large-scale plantations, it appears superior for smallholders and in the case of abiotic stressors (e.g. flooding, drought, storms), which can also affect conventional systems.

Finally, diversity enables the optimised resource use as described in previous sections. Structural complexity and associated diversity are schematically shown in

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[4] In contrast to temperate regions, where biodiversity increased in certain habitats since the beginning of agricultural use (MARTIN & SAUERBORN 2006).

[5] This is understood as gradual regulation down to a threshold population rather than total immediate control aiming at zero pest population as targeted by a pesticide approach.

figure 2, with agroforestry, permaculture and analogue forestry falling under the category of agroforestry as defined for this study.

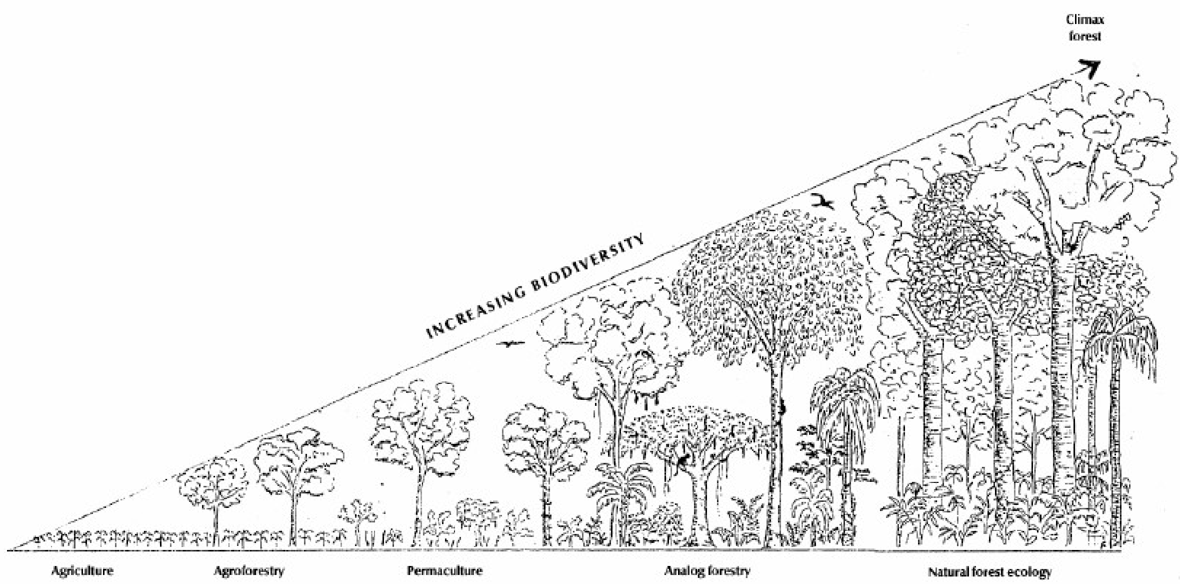

Figure 2: Analogue Agroforestry as sub-climax: The complexity of Analogue Forestry in relation to other forestry practices (DUFTY 2001)

Figure 2 shows that especially multi-storey systems can resemble functions of secondary forests, but also the wide range in diversity covered by different agroforestry systems.

3.2.4.2 Diversified production and multi-purpose trees

Similarly as for stressors, diversification in agroforestry products can be a strategy of economic risk minimisation. While low risk strategies may not be the appropriate entrepreneurial way of profit maximisation, smallholders are usually risk-averse, because they do not dispose of sufficient financial capital to gamble; total loss of a year's harvest is existential. With the increasing influence of world market fluctuations on local farmers' income[6], risk control by portfolio diversification is an issue for small farmers, even when additional marketing costs[7] are considered. On the other hand staggered biological cycles, planting, weeding, pruning and harvest interventions can reduce labour peaks, which can otherwise not be handled without hiring external labour. Especially for smallholders, who are not fully integrated into market economy or partly produce for subsistence, diversification of the diet is an important contribution to a healthy way of life. This is especially true in the case of fruit trees, which generate valuable supplement of vitamins to an often carbohydrate-biased diet.

In practice, the effort of raising trees is often justified by their multiple uses and products. Apart from the environmental services and soil productivity mentioned above, trees provide timber, construction material, shelter, fodder, fuelwood, fruits, flowers, fibres and medicine, form live fences and may attract animals that can be used in some or the other form.

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[6] shown by the recent food crisis, which has been at least partly triggered by the biofuel boom.

[7] These may arise from the variety of marketing channels needed to be opened or from the repeated transport of smaller amounts of commodities.

As an example, the role of leguminous trees or shrubs as protein banks for livestock has been highlighted. These are regularly pruned and the prunings fed to animals, while at the same time serving as living fence and improving the soil (Agroforestry and Multipurpose Trees and Shrubs R&D Team 2003; Nair 1993).

In this context, firewood production deserves special attention. Already in the mid 1970s more than 2.5 billion people in developing countries derived at least 50% of their energy demand from fuelwood. Scarcity of fuelwood around settlements is a common phenomenon and agroforestry systems are already very important fuelwood suppliers. Fuel wood on agricultural land can potentially cover >70 % of the primary wood energy demand of South- and South-East Asia (Jensen 1995).

In this context agroforestry-based fuelwood production can be an option to meet the increasing demand through social forestry and ‘green-belt’ programs, preferably on degraded (public) waste lands (Nair 1993).

4 Types of agroforestry systems

Innumerable systems and designs can be subsumed under the term of agroforestry. Among the attempts to classify the different systems the scheme of Nair (1987) considers various approaches and is presented here (table 1). Three basic sets of man-managed components – woody, herbaceuos and animal form systems of the primary classification of

1. Agrosilvicultural systems: Annual crops and shrubs / trees;

2. Silvopastoral systems: Pasture or cut fodder with animals and trees);

3. Agrosilvopastoral systems: Trees, crops, pasture / cut fodder and animals.

In a second step the systems are differentiated according to spatio-temporal arrangement, functions and organizational aspects.

Table 1: Categories of agroforestry systems (Nair 1987)

CATEGORIZATION OF SYSTEMS Based on their structure and function			GROUPING OF SYSTEMS According to their spread and management	
STRUCTURE Nature and arrangement of components especially woody ones		FUNCTION Role and/or output of components, especially woody ones	AGRO-ECOLOGICAL/ ENVIRONMENTAL	SOCIO-ECONOMIC AMD MANAGEMENT LEVEL
Nature of components	Arrangement of components			
Agrisilviculture (crops and trees incl. shrubs/trees and trees) Silvipastoral (pasture/animals and trees) Agrosilvopastoral (crops, pasture/ animals, and trees) Others (multipurpose tree lots, apiculture with trees, aquaculture with trees, etc).	In Space (Spatial) Mixed dense (e.g.: Home garden) Mixed sparce (e.g.: Most systems of trees in pastures) Strip (width of strip to be more than one tree) Boundary (trees on edges of plots/fields) In time (Temporal) Coincident Concomitant Overlapping Sequential (separate) Interpolated	Productive Function Food Fodder Fuelwood Other woods Other products Protective Function Windbreak Shelterbelt Soil conservation Moisture conservation Soil improvement Shade (for crop, animal, and man)	Systems in/for Lowland humid tropics Highland humid tropics (above 1,200 m a.s.l; e.g.: Andes, India, Malaysia) Lowland subhumid tropics (e.g.: savanna zone of Africa, Cerrado of South America) Highland subhumid tropics (Tropical highlands) (e.g.: in Kenya, Ethiopia)	Based on level of technology input Low input (Marginal) Medium input High input Based on cost/benefit relations Commercial Intermediate Subsistence

Following Nair's classification, the most relevant systems appropriate for smallholders are explained to more detail below along a gradient of intensification. Differences in ecosystems are not emphasized here as climate and soils affect species composition and planting density rather than the general system design. A focus is laid on systems that mimic natural ecosystems as they are most suitable to exemplify principles of agroforestry.

4.1 Extensive systems

Extensive forms of tree–crop associations have been used by indigenous peoples for millennia in different parts of the world. Local knowledge of soils and plant species played an important role in most of these systems. These ancient systems include semi-nomadic types of forest clearings on preferred spots of fertile soils or selective planting along frequently used trails (e.g. Hecht & Posey 1989; Balée 1989 for the Amazon; Conklin (1957) for the Philippines). Enrichment planting as practised by forestry authorities (e.g. in Peru and the Philippines) may be an adoption of such early patterns. These systems have been investigated to demonstrate the gradual transition between agroforestry and natural forests and the possibility to practice sustainable close-to-nature forms of agriculture; it has been argued that the presumably virgin Amazon has been inhabited and agriculturally used by more people than nowadays without major negative impact; sustainable land use is seen as a form of conservation. Early forms of tree domestication stem from these ancient systems and immense knowledge has been passed over many generations of agroforesters. Traditional systems often include hunting and gathering as central elements. Deliberate planting of annual crops such as maize in forest clearings in order to attract animals for hunting have been reported from Bolivia[8].

4.2 Sequential and semi-simultaneous systems

In a broader sense, a system can be understood as a long term development, which includes annual and perennial elements in the course of time, but not necessarily simultaneously.

As a prominent example, taungya, a forerunner to modern agroforestry similar to the German principle of *Waldfeldbau*, is based on the planting of (usually annual-biennial) cash or food crops between newly planted forest seedlings in reforestation schemes. Farmers raise crops while the forest trees are still young. After 2-3 years, depending on the tree species and spacing, the canopy closes, and light-demanding annual crops can no longer be planted. The final vegetation is a pure tree plantation. Farmers then transfer to other open areas to repeat the process. This can be applied by using different reforestation species. Originally invented as more sustainable alternative to shifting cultivation the modern taungya system may differ significantly from the original concept. Ideally, the system permits sustainable use of forest land for food production by landless people who would otherwise be engaged in forest encroachment (NAIR 1993; ENABOR ET AL. 1981).

Other semi-simultaneous systems include improved fallow schemes usually based on woody leguminous species like *Gliricidia sepium*, *Flemingia macrophylla* or *Calliandra calothyrsus*. These can be planted sequentially or overlapping with annual cash crops. Different types of improved fallow systems in Kenya have been investigated by WALKER (2007) and CHUKWUMAH ET AL. (2008) regarding nutrient cycling and economic balances.

The improved fallow system aims at improving traditional shifting cultivation in many parts of the world. Many lessons have been learnt from short-term improved fallows (<5 years duration). These include the preference of woody over herbaceous leguminous species, utilization of dry seasons unfavourable for crop production, strategic use of nitrogen fertilizers and the importance of phosphorus. Additional services provided by fallows include fuelwood and fodder production, recycling other plant essential nutrients, weed suppression and improved soil water storage (SANCHEZ 1998).

The concept of nurse trees or tutors makes use of the shading effect of trees or shrubs on slow-growing forest trees that cannot tolerate full sunlight. The nurse tree is usually later removed to avoid competition once the slow growing (usually high value) tree has reached a certain height.

Other crop rotations like relay cropping are frequent that include overlapping cultivation periods to reduce the time a bare soil is exposed to erosion or weed

[8] authors' information from local farmers and extensionists

invasion. Intercropping with repellents, trap or catch crops is used to keep pests, diseases or parasitic weeds away from cash crops. However, these approaches are not confined to agroforestry systems.

4.3 Spatially differentiated systems

As for the temporal dimension, the understanding of the spatial term 'system' can differ significantly between designers. An agroforestry system can spatially range from a backyard garden over the plot and farm level to large plantations or the landscape level. Here spatial zoning refers to plot level.

Probably the most well-known approach of spatially differentiated agroforestry is hedgerow planting. The term describes vegetation strips planted along contour lines of slopes in order to reduce soil erosion. Hedgerows are planted to trap sediments and reduce surface runoff velocity. After a few years, terraces are formed. Common hedgerow species are *Leucaena leucocephala* and other shrubs of dense habitus, but also grasses like *Vetiveria spp*. Hedge shrubs and trees, apart from soil conservation, have multiple uses such as food, feed or fuelwood. The beneficial effects of hedgerows have been broadly investigated under different aspects (PANSAK ET AL. 2008). Adoption of hedgerows by farmers can be limitied due to competition of the perennial component and the crop. Benefits provided by the hedgerow should clearly and measurably exceed investments in labour and planting material and trade-offs in occupied space and competition for water, nutrients and light. Thus, species selection should consider competitive potential and value of the hedgerow species.

Figure 3: Hedgerow Intercropping[9]

Windbreaks have a similar function as hedgerows, but are employed against wind erosion. Spatial layout matters with respect to distances as well as angle to the main wind direction. Species can include trees, shrubs, and vines to protect croplands from strong winds, especially in semi-arid and arid areas. They can provide protection to crops over a distance equivalent to 15-20 times the height of the trees in the windbreak (PCARRD 2003, SUDMEYER & SCOTT 2002). Apart from reducing erosion, wind breaks can decrease evapotranspiration of the crop component.

[9] source: http://genomics.nottingham.ac.uk/~Zoe/pslab/black/hedgerowintercrops.jpg

Figure 4: Contour planting: Overstorey trees with wheat in Uganda[10]

The term shelter belt, still mainly used for windbreaks, has recently been used to describe tree belts along coastlines that are capable to protect people from tsunami effects (MAROHN ET AL. 2008). As for riverbank stabilisation, these elements do not necessarily include an annual component; however, they should provide measurable benefits to be adopted by farmers.

Planting of multipurpose trees and shrubs as boundaries around the farm and along road sides is also a very common practice. They provide protection, privacy, and valuable products to people. Trees are planted within property line as fence or as demarcation of farm lots. Most fences have at least one additional use. Depending on the farm type, fences can be composed of *Cactaceae* (protection), *Artocarpus sp*. (providing fodder for pig breeding), *Erythrina spp*. (shade, mulch, fodder) or other species (s. fig. 5).

Figure 5: Fence systems in Bali, Indonesia: Left side Erythrina fence, fodder grass, cow stable, banana, coconut; right side cactus-based

The permaculture design concept builds on establishing different zones on a farm property. Zones depend on distance to the homestead (i.e. labour intensity,

[10] source: http://genomics.nottingham.ac.uk/~Zoe/pslab/black/Kenya.jpg

transport) and so-called guilds of plants, which fulfil different (ecological) functions. While intercropping is part of permaculture approaches, some tree-based design elements are intercalated rather than thoroughly mixed with other elements.

4.4 Animal-based systems

These include a wide range of silvopastoral and agrosilvopastoral systems as explained above. Silvopastoral systems are combinations of woody perennials with livestock production. Following the narrrow definition of agroforestry, silvopastoral systems are not necessarily agroforestry, as they may contain no annual component. The same is true for cut and carry systems that include fodder from hedgerows or grass strips. Systems differ significantly depending on farm size: Classical tree-cattle systems in Latin America often consist of wide-spaced palm trees (e.g. coconut) and improved pasture with *Brachiaria spp*., other grasses or herbaceous legumes. A widely used system more dimensioned to the smaller farms in Southeast Asia consists of a central patch of cash crops and/or pasture surrounded by hedges of leguminous fodder shrubs and a second belt of fruit or timber trees (s. fig. 5, left side). Some subcategories are listed in the following paragraphs.

Livestock-under-tree

Animals (e.g. cattle, sheep, goats) are allowed to graze freely underneath the relatively mature tree plantations. These plantations are for wood or fruit production.

An example of a silvopasture scheme run by a timber company in the Philippines is described by the Agroforestry And Multipurpose Trees And Shrubs R&D Team (2003). The cattle is allowed to graze under *Aleurites moluccana* trees, where improved forage grasses are grown. The cattle keeps the grasses trimmed, facilitating recollection of the fallen *lumbang* nuts. The cattle dung scattered over the plantation area serves as organic fertilizer and cattle meat as major source of income.

Hedgerows and improved pasture and/or fodder trees / shrubs

Hedgerows of fodder trees or shrubs (e.g. *Desmodium rensonii*, *Leucaena leucocephala*, *Gliricidia sepium*, *Flemingia spp*., *Sesbania sesban*) are planted at certain intervals. The strips between the hedgerows are grown with improved pasture grasses and/or other fodder shrubs. Prunings from the hedgerows, grass and fodder trees/shrubs are fed to animals held in corrals (Agroforestry And Multipurpose Trees And Shrubs R&D Team 2003). A second option is to grow the hedges as delimitation of compartments of pasture. Animals are allowed to subsequently graze a single compartment for a certain time, while the other areas regenerate.

Agrosilvopastoral systems

Agrosilvopastoral systems are usually combinations of annual crops, woody perennials, and livestock. Many combinations are possible and used, a common denominator being minimisation of damage to crops caused by animals. As an example, in the Northeastern Brazilian Cerrado, a sparsely vegetated semi-arid region, where cattle and goats serve as insurance for prolonged dry periods, kilometre-long wooden fences keep animals out of crop fields. In mixed systems of maize, cotton and Leucaena, cattle enters the plot only after maize rattooning[11].

In another variant, the initial cropping combinations include tree seedlings and annual agricultural crops as in the taungya system. As the trees grow and the canopy

[11] Rattooning describes partial harvest, only the cob is taken out, while the vegetative part remains on the plot.

closes, annual crops are shaded out. Instead, shade-tolerant grasses and vines take over covering the ground where animals are allowed to graze freely as in any livestock-under-tree system.

The concept can be extended to multistorey systems with grazing animals. As an example, coconut-lanzones[12] schemes, with horses or cattle grazing can be observed in Luzon, Philippines (Agroforestry And Multipurpose Trees And Shrubs R&D Team 2003).

4.5 Intensive systems

This category is usually characterised by higher inputs in labour, higher diversity of plant species and higher structural diversity compared to the aforementioned systems. In smallholders' farms and according to the permaculture design principles, patches that require intensive care (diversified cropping times, theft, damage, pests) or contribute fresh produce to the diet are located close to peoples' homesteads.

4.5.1 Home gardens and multi-storey systems

Homegardens are looking back on a long tradition in many geographic regions and have been widely studied, by agronomists and extension workers as well as ethnologists and ethnobotanists. A meticulous description of Amazonian home gardens, species, their uses and propagation has been given by Breckling & Birkenmeier (2000). Home gardens usually consist of an intimate assemblage of multipurpose trees and shrubs with annual and perennial crops and various livestock within the compounds of individual houses, with the whole crop-tree-animal unit being managed by family members. Products are primarily intended for household consumption but gardens also have considerable ornamental and microclimatic value (Nair 1993).

Contrary to homegardens, multi-storey tree gardens are usually more remote from homesteads and also found on communally-owned lands surrounding villages (Nair 1993). The system is characterized by randomly mixing various, mostly multi-purpose species that create at least two layers of canopy. It mimics forest structure with all attendant advantages. The upper canopy is composed of light-demanding species, while the understorey is made up of shade-tolerant species. A design of a multi-storey plot of 1ha is shown in fig. 6. Apart from manila hemp[13], fruit trees and indigenous timber trees were combined in a regular gridded pattern. Annual cash crops were not included in this scheme as the plot is distant from the village. For most systems it is advisable to include a soil cover like *Pueraria phaseoloides*, *Desmodium spp*. or other creepers to prevent soil erosion during the initial period after planting.

[12] *Lansium domesticum*, a popular fruit.

[13] *Musa textilis*, a close relative of the banana, is used for fibre production.

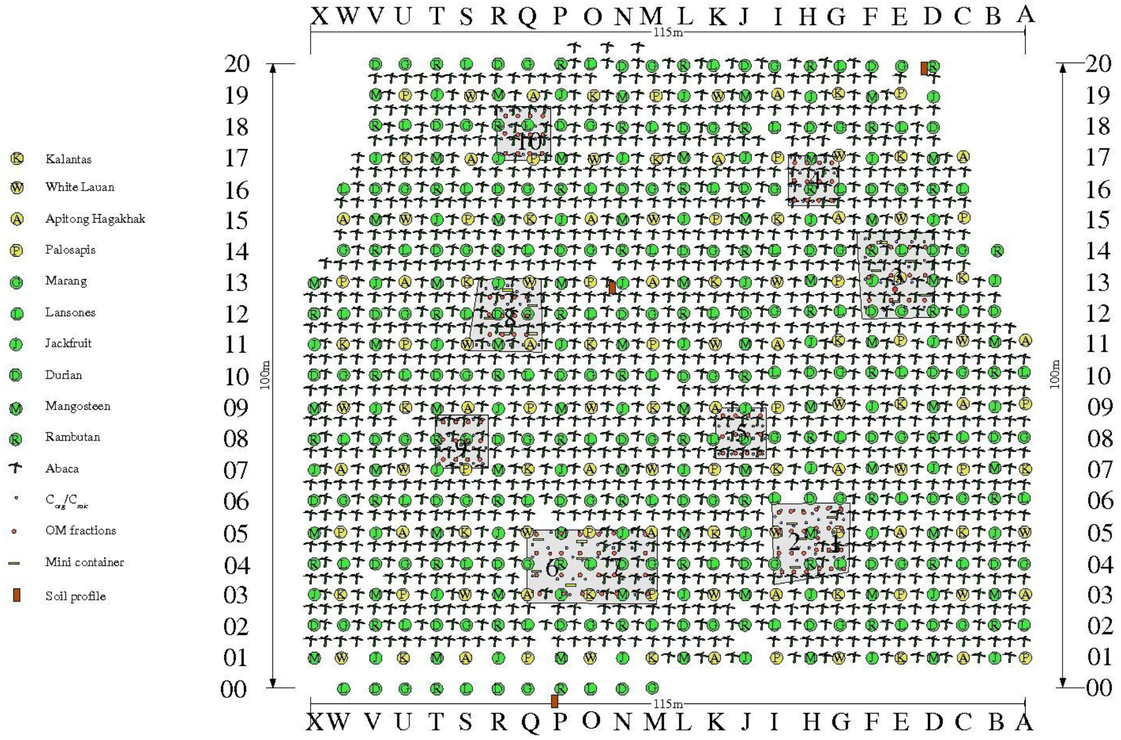


Figure 6: Lay out of a multi-storey system in Leyte, Philippines (MAROHN 2007).

A certain proportion of tropical plantation crops is grown by smallholders, sometimes grown as forest species (e.g. cocoa in Trinidad or Bolivia or coffee in Ethiopia) or in integrated cropping systems, e.g. rubber in Nigeria, banana-coffee smallholding in Eastern Africa or coconut in Asia and Oceania (NAIR 1993).

On the other hand, integrated land-use systems with plantation crops or intercropping of perennials with annual crops are usually limited to smallholder agriculture. In modern large-scale plantation systems like coffee, tea, rubber or oil palm, which have been developed with the single-commodity objective, multi-purpose resource use and diversified production strategies are considered impractical. Thus technology development to make such alternatives economically attractive has largely been neglected.

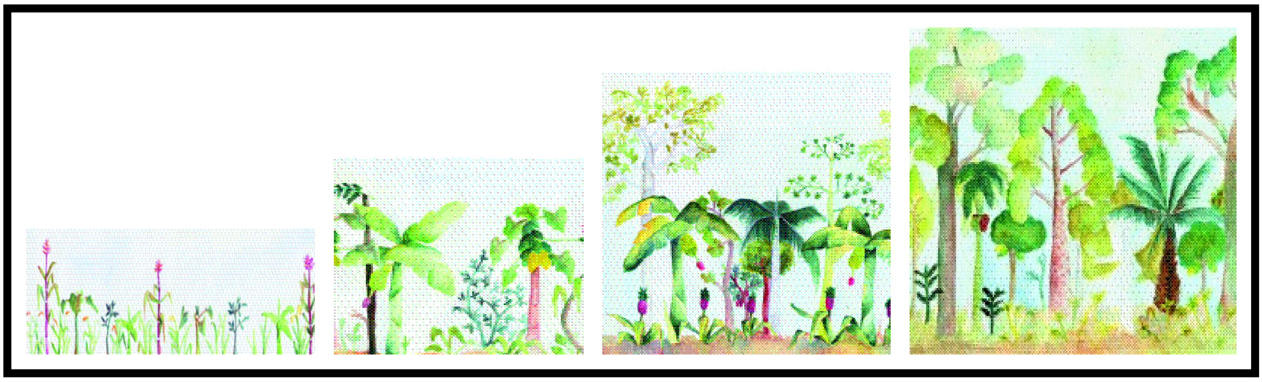
4.5.2 Successional systems

Natural succession describes the sequence of vegetation colonising a given ecosystem. While species composition may vary due to given environmental factors on site, the general sequence starts with pioneers, transgresses several intermediary stages and reaches a relatively stable site-specific climax vegetation. While pioneer stages are characterised by low standing biomass, fast growth and low species diversity, climax vegetation at potential forest sites has high standing biomass, slow net growth and – at least in tropical rainforests – high biodiversity (ODUM 1969).

While e.g. a rice field can be compared to the pioneer stage of a natural ecosystem, successional agroforestry systems are designed to mimic the entire course of natural succession in an accelerated way. It is assumed that, copying natural evolution on site, the climax stage represents the most adapted system to cope with prevailing environmental conditions, making best use of available resources and disposing of the highest possible stability, stress-resistance and resilience in cases of disturbance.

Regeneration of soil fertility is part of succession as biomass production, litter deposition and more balanced microclimate lead to build-up of soil organic matter. In agriculture, fallow is the process allowing natural succession to fulfil this function and in agroforestry accelerated regeneration under improved fallow is a major goal.

Principles of agricultural systems mimicking natural succession have been summarised by Ewel (1999), Milz (2001) or Margraf & Milan (1996). As the canopy closes (fig. 7), species composition changes towards shade tolerant plants.



Year 1	Years 2-3	Years 5-10	Years >20
Maize	*Inga spp.*	Cocoa, coffee	Cocoa
Beans	Pineapple	Peach palm	Brazil nut
Cassava	Papaya	Citrus, Annonaceae etc.	Vanilla
Maracuja	Div. bananas	Div. banana	Palm fruits and NTFP
Sesame	Coffee	Fast growing wood	Hard wood

Figure 7: System habitus and some important products in a schematic Latin American successional agroforestry system (illustration Yana & Weinert 2001)

Ancestral successional systems are known from several parts of the humid tropics (for an overview of Amazonian systems see Posey & Balée 1989). In the Philippines, traditional Hanunóo agriculture first described by Conklin (1957) represents a form of successional agroforestry. Hanunóo agriculture integrates cocos and areca palms, cocoa, malay apple, jackfruit and mango trees, bamboo and abaca after a first phase of annuals and banana. The system uses a high diversity of food and non-food plants (a total of 89 genera has been counted). Fallow periods traditionally last from 1 to 20 years – depending on soil and plants – with an average of 12 years[14]. After 30 years there is little difference between the secondary and primary forest; trees can then be as high as 30 to 40 m (Bahuchet 1992). Two hectares of land are deemed necessary to keep a balance between cultivation and fallow.

The theoretical framework of **rainforestation** assumes, that imitating the natural climax vegetation in physical structure and species composition leads to the most resilient possible land-use. Basic principles of rainforestation are the at least 3-storey structure and focus on native species. It is recommended to plant representatives of four guilds of plants – lumber, fruit trees, climbers and shade-tolerant tuber crops (Margraf & Milan 1996). A standardised planting pattern has deliberately not been

[14] 7 or 8 years is standard, less for bamboo; 10 to 20 years are ideal for cereals; 20 to 25 years allow for proper regeneration and a secondary forest.

proposed; concerning planting distances and choice of species, the scheme may be modified with respect to farmers' preferences, site characteristics and availability of seedlings. Initially, exotic fast-growing 'miracle trees' like *Gmelina spp*., *Acacia mangium*, *Swietenia macrophylla*, *Eucalyptus spp*. were used in rainforestation. Due to reports of higher resistance to typhoons, pests and diseases, focus shifted more and more towards native – especially high-value Dipterocarpaceae – species and resulted in a total ban of exotic trees (Margraf & Milan 1996). An important lesson from early rainforestation experiments was to distinguish pioneer and shade-loving trees, the latter ones being planted after the establishment phase of their tutors (usually in two subsequent years). Rainforestation has been implemented as a showcase technique and been highly subsidised from the beginning: Farmers received all inputs including work force and relied on so-called livelihood programmes, i.e. payments that compensated for the establishment of the plots. Although biophysically promising, only a few hectares of rainforestation still exist after more than 10 years in the area.

Sistemas multi estrato (portuguese for multi strata systems) have been promoted by development agencies in Brasil, Bolivia and Peru. They stress the role of successional phases and mutual positive influence of plant guilds. High diversity of species belonging to all successional stages make optimum use of all niches and high biomass production of the system is fed back through pruning and mulching. Apart from the tight nutrient cycle, so-called dynamisation is an important element of multi estrato. Apart from a tutoring role it is assumed that plants in the late generative phase (maturity) will negatively affect plants in vegetative growth. Consequently, synchronisation of planting times is crucial and pruning, apart from recycling biomass, has the effect of eliminating plant parts that would slow down vegetative growth of other plants in the system. Selective weed management links up to this approach: Only such plants that have negative effects are eliminated, others are tolerated. This approach goes hand in hand with the goal to keep the soil covered permanently. However, selective weeding requires in depth knowledge of plant species. Pests and diseases are seen as indicators for suboptimal successional processes in the system, they are treated by means of plant management. As for rainforestation, multi estrato totally bans burning for field preparation. Although breaking with some conventions and not being easy to understand for beginners, investments of the development agency in a pedagogic concept and participatory approach rather than subsidies have led to relatively high identification of farmers and dissemination of the system. However, adoption of rainforestation and multi estrato cannot be directly compared, mainly due to the different size of typical 'smallholdings' in Southeast Asia and Latin America.

Analogue Forestry principles have spread from Sri Lankan forest gardens - highly productive and diverse small plots located near homes in rural communities. Analogue forestry systems may contain exclusively native but also exotic species (Jones 2001). They represent complex and holistic forms of agroforestry that seek to maintain a functioning tree-dominated ecosystem while providing broad range of marketable commodities that may include fruit, nuts, herbs, cut-flowers and cut-foliage, pharmaceuticals and timber. The production system is built up in layers over successive years while off-setting the establishment costs for the next layer (e.g. shrub) by the sale of commodities from harvests of the previous layer (IAFN 2007, Dufty 2001). Analogue forestry arose in Sri Lanka around 1981 as an alternative to monocultures of *Pinus spp*. and *Eucalyptus spp.* and has spread to India, Vietnam, Philippines, Australia, Peru, Ecuador, Colombia, Brazil, Costa Rica, Dominican

Republic, Honduras, Mexico, Canada, Kenya and Zimbabwe at present. The International Analog Forestry Network as umbrella organisation has established own certification standards (Senananyake 2007).

5 The socio-economics of agroforestry

Beyond the described biophysical functions, agroforestry is often associated with a vision of sustainability in terms of social, economic and ecological long-term wellfare. As mentioned, the agroforestry definition of the World Agroforestry Centre reads as follows:

'Agroforestry is a dynamic, ecologically based, natural resources management system that, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels.'

Farmers usually have a very keen sense of sociocultural aspects and economic short- and mid-term profitability of a land use option. Agroforestry projects can only be sustainable[15], if these criteria are met.

5.1 Knowledge base and sociocultural frame

While many typical functions and design principles are universal, agroforestry strongly resorts to indigenous knowledge when it comes to tree-site matching, i.e. identifying the most promising species for a given spot. Designing agroforestry systems needs to take spatio-temporal patterns of resource demand into account (s. 2.2.1). This includes knowledge of local soils and their respective rootability, nutrient and water resources, knowledge of local climate and plant species as well as cultivars. Indigenous farmers usually dispose of this knowledge, they know about distribution of different soil types and the most appropriate relief position for each plant species as well as sowing/planting dates and peculiarities of the local climate. Locals also know about dietary preferences and demand of certain products on the market. Any project planner will greatly benefit from making use of participatory techniques and integrating peoples' knowledge into system design *before* implementation. Once the sociocultural framework of a system and its projected economic outcomes coincide with peoples' concepts, innovations can be implemented. Only when acceptance of the system is attained, the project has the potential to succeed.

Ideally, agroforestry integrates a wide range of traditional practices that have been validated and adapted to local conditions over generations. Sustainable management and protection of the natural resource base by native and peasant communities is often an integral part of their livelihood strategy (Prins 2000).These practices are part of the cultural heritage and identity. Consequently, integrating local knowledge is expected to improve ownership, i.e. identification of the target group with the project goals. While building on traditional knowledge has the effect of valorisation of the local cultural background, care needs to be taken not to impose 1:1 copies of a practise to different environments, e.g. in the case of settlers or migrants from different ecosystems. While the principles are generic, concrete steps are mostly site-specific.

Traditional practices are often stigmatised as backward and underdeveloped. Extensionists, researchers or media may have implanted the paradigm of development being equivalent to intensification, mechanisation or high input agriculture. Convincing farmers of the preferability of a locally adapted low-input system can be demanding, especially where the alternative draft is a highly profitable

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[15] In this context, sustainability means having sustained impact beyond the project cycle.

well-ordered high tech scenario as advertised in brochures of agroindustrial companies, green revolution advocates or even some development agencies. High input systems are unlikely to be appropriate for small farmers without much financial capital resources.

However, modern technologies can be of relevance, when potentials of different agroforestry scenarios are explored and compared among each other or against alternative land uses. Technologies improving the knowledge base for land use planning include remote sensing data and derived geographic information (like slope, exposition, wetness index and other factors) as well as all kinds of specific data bases (e.g. climate data, soil maps or inventories, geological maps etc.). Spatially explicit dynamic modelling can help substantially to project alternative land use options and *a priori* assess environmental impacts. Soil degradation and rehabilitation, water balances or farmers' decisions can be predicted using validated models. These techniques can theoretically be used in a participatory way with farmers, but are usually employed in workshops with planning authorities. Innovative means of communication between users and exchange of ideas can also contribute to the success of a project.

Regarding implementation of agroforestry plots above a certain size, a cultural context that builds on community work can be very advantageous. In a group of 10-20 persons clearing, mulching and planting a typical smallholder agroforestry plot of a quarter hectare can be carried out within one day, which has a motivating effect. Ideally, each farmer would bring a collection of seeds or cuttings from his farm. During work, social exchange takes place and farmers can learn from each other. For a development agency or NGO, these meetings can be used to disseminate novel techniques.

5.2 Food security, nutrition and health

Diversification is the key not only to system resilience against pests and diseases, to crop failure and economic risks, but also to a balanced diet that includes vitamins, trace elements, proteins and other important substances in a balanced ratio.

Food security-oriented approaches are particularly appropriate for resource-poor farmers, who don't dispose of the necessary financial means to buy commodities in the market. A diversified agroforestry plot can serve as the grocer's shop and pharmacy of poor farmers.

Linkages between agroforestry, health and nutrition have been summarised in four categories by Swallow & Ochola (2006):

- Supply of medicinal plants to prevent and combat diseases; many rural communities rely to large extent on natural remedies especially for serious long-lasting diseases that require continuous supply with medicines;
- nutritious food; e.g. home gardens are used by children to harvest fruits and play near the homestead;
- generation of income from diversified sources and saving of inputs that would otherwise need to be purchased (timber products, dyes, cosmetics, fibres etc.);
- creation of environmental conditions beneficial for human health (e.g. microclimatic conditions that are perceived comfortable by man and are not

conducive for mosquitoes, certain bugs or other transmitters of infectious diseases).

5.3 Economics

A biophysically optimal solution does not necessarily coincide with the most profitable one. The art of agroforestry design is to combine both, as e.g. in improved fallow systems in Kenya, which have been investigated from the perspective of nutrient supply (WALKER ET AL. 2008) and rentability (CHUKWUMAH ET AL. 2008). For smallholder systems, which are usually at least partially subsistence-oriented, production of staple food is a priority. Apart from this basic necessity, there are many options to improve income generation from agroforestry systems, which have been discussed in literature in recent years (e.g. valorisation of neglected crops).

5.3.1 Production factors, inputs and outputs

In general, **inputs** for agroforestry systems do not differ much from those required for other agricultural systems. The most distinguishing factor is probably labour: For initial field preparation, especially when burning is not an option, labour requirements are high. Depending on the planting pattern, initial weeding between rows may also be more time-demanding than for monocropping systems. This factor drops dramatically once the system is well established. As soon as the canopy closes and shades out weeds, very limited work is needed. If the system has been designed wisely, even (re)planting is very limited, so that the main labour inputs are spent on harvesting.

As one of the most crucial preconditions for implementing multi-storey systems, land area must not be limiting. Land has to be owned by the farmer (otherwise he / she would not invest in trees) and area has to be sufficient to guarantee the production of staple crops[16] alongside the agroforestry system during the later closed canopy stages. However, the existence of agroforestry *per se* seems not to depend on farm size as can be observed in densely populated regions like central Java[17]. It is more the type of agroforestry design that is influenced by farm size. Fertile densely populated areas seem to tend to open areas planted to light demanding annuals surrounded by hedges or trees (e.g. rice paddy with trees planted on the bunds), while in areas where land is not constraining pure cropping fields are often separated from mixed stands. Design considerations may substantially differ in regions where land is limiting compared to those where labour is limiting.

Several low input versions of agroforestry exist, that can be adequate options for resource-poor farmers. Seeds or cuttings of local varieties are usually available and can be exchanged between farmers. Mostly smallholder agroforestry is low tech and linked to zero tillage as a soil conservation technique. Tools required are the usual machetes every farmer owns and a common sharpening stone. A piece of paper to draw the design and cords to delineate the planting rows complete the toolbox. Sticks to mark tree positions and hooks for weeding are usually cut on site from bamboo or shrubs.

Diversified plots have the advantage to supply a variety of **outputs**. A proper design considers the sequence and timing of labour peaks as well as harvesting dates, processing and marketing of products. A schematic representation of a diversified

[16] usually annual light-demanding

[17] with admittedly very fertile volcanic soils that allow dense planting

system design rendering continuous outputs during the entire rotation is shown in figure 8.

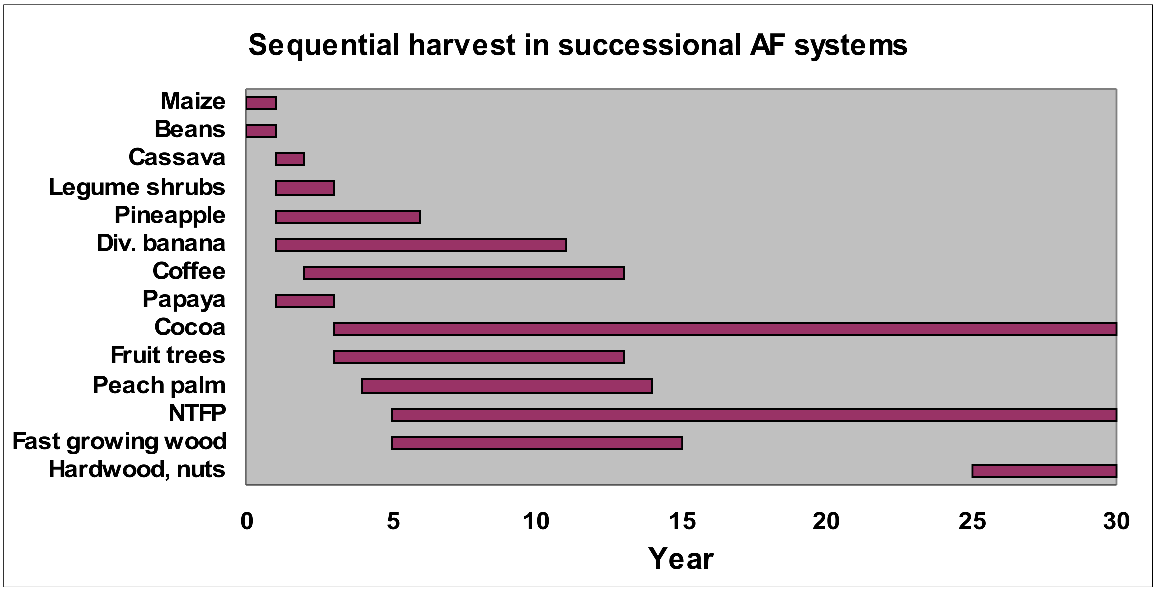

Figure 1: Schematic harvesting sequence in a Latin American successional agroforestry system

In addition to subsistence goods, diverse agroforests provide farmers with a cash income through a wide range of marketable and sustainable high value products such as resins, fire wood, fruits, animal fodder, medicinal plants high-grade timber and animal products (RETNOWATI 2003).

5.3.2 Rentability

Despite continuous yields the economic balance of agroforestry systems can be negative during the initial period (see figure 9). This is owed to the inputs in seedlings and particularly labour during the first year. The establishment phase is crucial to most systems. Especially tree seedlings need permanent attention, protection against direct sunlight, aggressive weeds or pests like rodents or insects.

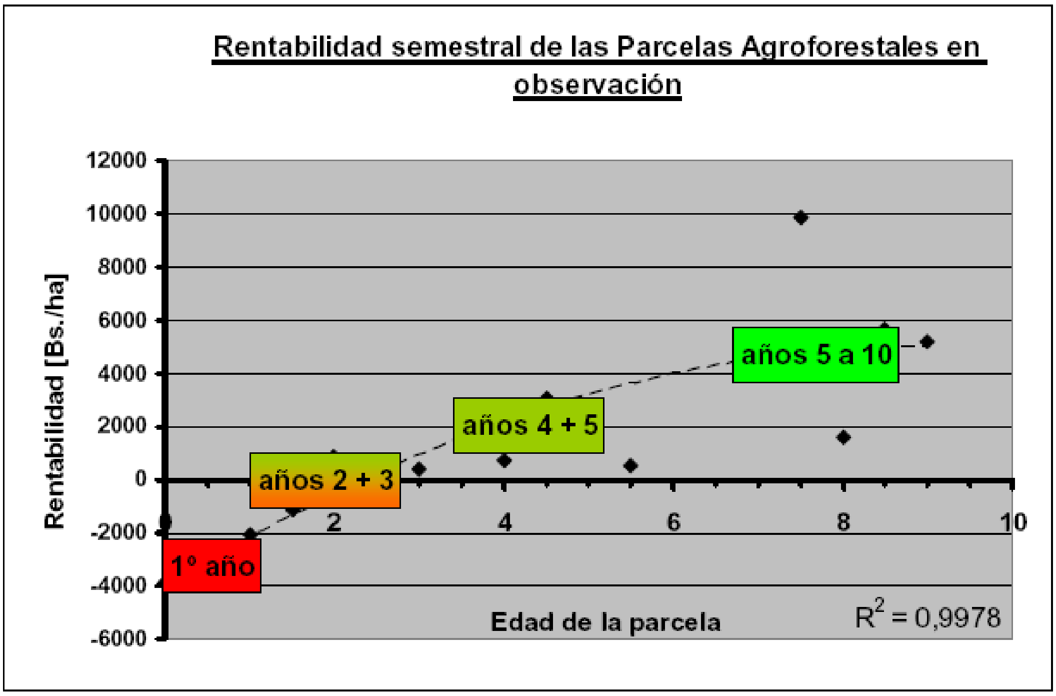

Figure 2: Interpolated rentability of multi-strata plots in Bolivia over ten years. X-axis represents age of plot [years] and y-axis rentability [Bolivianos/ha][18] (Schnatmann 2006)

Regarding the time span to break-even, small farmers are usually short in cash and depend on short term cash-flow. Thus, for the adoption of a specific system preference will be given to those systems that require low financial investment while providing short-term positive cashflow (Lojka & Loikova 2008). This principally favours the adoption of low-input agroforestry systems. On the other hand, farmers cannot afford to invest labour or allocate land area without getting returns at the end of the same growing season. The potential of projected superior performance after several years (due to significantly decreased labour intensity) may not be realised due to short-term limitations in liquidity.

Agroforestry principally has the potential to deliver short term income if annual species are grown in combination with the trees. A sustainability assessment of different agricultural land use systems in Indonesia (Tarigan & Suria Darma 2002) revealed a 14% higher return to labour and shorter-ranged positive cashflow of coffee- and rubber-agroforestry practices compared to perennial monocultures (coffee, rubber, oil palm).

5.3.3 Resource use and risk management

Dependency and subsistence: Studies from the Philippines show that agroforestry households source up to 90% from their farm, home gardens and livestock. Agroforests offer the opportunity to better meet the needs for subsistence, increased food security and thus reduce the dependence on external purchase. Diversified agroforestry systems offer good options to bridge food shortages in times were main staple food products are not available (Macandog et al. 2005).

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. This excludes the initial establishment of the system, where slashing without

[18] The validity of interpolation and r^2 may be questioned under the given spread; this example was chosen, because it shows a common tendency based on real field data.

burning and or sophisticated planting designs may demand more time than field preparation for monocropping systems. In later stages, selective weeding as recommended by multi estrato experts may require more time than conventional weeding.

Apart from these peculiarities, labour can generally be reduced through mechanisation, but as stated before, agroforesters are often limited by financial capital.

Risk: Especially on degraded sites with resource limitation diverse assemblages of agroforests have a greater likelihood to adequately respond to limited resources than species-poor assemblages (Kumar 2006). The ecological advantage of trees and forests is gaining increasing relevance in the context of climate change, as trees are deep rooted and have large reserves, and thus are less susceptible than annual crops to inter-annual variability or short-lived extreme events like droughts or floods. Thus, trees offer diversification options that can reduce production risks for small holder farmers. The monetary risk when loosing crops or of dropping producer prices can also be reduced by diversification of marketable products (Padoch et al. 1985) and multi-purpose use of trees.

5.3.4 Comparing profitability of mono- and intercropping

Tree components in agroforestry systems are often for multipurpose use, contributing more than one significant product, commodity, service or function within the respective land use system (Huxley & Wood1984). Based on classical economic indicators such as cost-benefit analysis or NPV, productivity and profitability can be compared between intercropping and monocropping options at a given site using the Land Equivalence Ratio (LER). Under the same management level the following term is used to determine the LER:

$LER = \sum Yp_i/Ym_i$,

where each Yp_i describes the partial LER for yields obtained under policulture (i.e. intercropping) and Ym_i yields obtained under monocropping (i.e. pure stands). A ratio >1 indicates a comparative advantage of the intercropping system, while for LER <1 pure stands are more productive / profitable. The quotient is read as the relative area under monocropping needed to obtain the same output as under 1 area unit of the mixed system.

Case studies in various developing countries show that agroforestry systems – besides providing valuable ecological and social services – can be financially more profitable than pure stands – and in many cases also more profitable than clear-cutting or extractive and low intensity logging forest use.

In a Peruvian rainforest study Peters et al. (1989) found a combination of selective logging, fruit and latex harvest more than six times more profitable (in terms of NPV at 5%) than clear felling.

In the case of multi-strata agroforestry and traditional monocropping agriculture in Bangladesh analysed by Rahman et al. (2007), agroforestry was substantially more profitable in terms of Net Present Value (NPV), Benefit-Cost-Ratio (B/C), Internal Return Rate (IRR) and Annual Net Cash Rate (ANCR) than the traditional system.

However, these examples are case studies and can hardly be generalised without taking all circumstances into account. In many cases weather, site, species, variety-specific differences or other local settings may tip the scale towards either option as the following example shows: BERTOMEU (2006) compared profitability of pure maize to fast growing timber species (*Gmelina arborea, Eucalyptus deglupta*) intercropped with maize and concluded that relative advantages depended on timber productivity to compensate competition. *Gmelina* turned out to be very competitive and strongly reduced maize yields.

5.3.5 Payments for Environmental Services (PES) and CDM

In most developing countries, 70 to 80 percent of the population are rural dwellers relying on forest lands and subsistence agriculture for their livelihoods. Some 1.2 billion people depend directly on a variety of agroforestry products and services (IPCC 2000). The assessment of the socio-economic functions and performance of agroforestry systems should not be restricted to conventional economic criteria and approaches such as yield, cost-benefit analysis and net present value. Internalisation of agrobiodiversity management, carbon sink value, improved nutrient cycling or integrated pest management, among others, may turn these systems into potentially highly profitable ventures. Additionally, the merits of agroforestry systems in terms of subsistence food for families, flexibility in production, reduced external-input requirements, enhanced aesthetic, landscape-, and societal values play an important role in the context of a valorisation of their socio-economic performance (TORQUEBIAU & PENOT 2006).

In context with the Kyoto protocol, the Clean Development Mechanism (CDM) has been created, that allows developing countries to obtain tradeable Certified Emission Rights (CER) for measures capable to generate *real, measurable and long-term benefits related to the mitigation of climate change* (Kyoto Protocol). Many developing countries are members to the UNFCCC and have nominated a Designated National Authority responsible for handling CDM issues; these countries have the right to generate CER. Activities eligible for CDM need to fulfil certain criteria like additionality, permanence, absence of leakage. Agriculture is principally not eligible for CDM measures, but afforestation and reforestation (A&R) schemes are. The concept of 'forest' underlying the Kyoto protocol's terminology of deforestation, afforestation and reforestation has been criticised as not targeting the goal of C sequestration. A terminology more directly linked to actual C stocks (rather than 'forest' and 'non-forest') would have directly qualified 'agroforestry' for carbon credits (VAN NOORDWIJK ET AL. 2003). However, agroforestry projects are eligible under the umbrella of forests, which again can differ between countries.

Mitigating effects are created through and quantified as biomass carbon sequestered from the atmosphere, thus reducing atmospheric concentrations of the greenhouse gas CO_2.

Biophysically, many agroforestry schemes, compared to a business as usual baseline of carbon stocks, undoubtedly have the potential to participate in CDM schemes. In this context, soil carbon stocks are paramount, which favours agroforestry related practices such as no burning, minimum or zero tillage, high biomass production and conservation / accumulation of soil organic matter (MAROHN 2007). Upscaling approaches have come to considerable potential of agroforestry for CDM: Carbon stocks assessment made on agroforestry systems in the Philippines found that carbon density ranged between 93 and 215 tC/ha (PULHIN & LASCO 2007) at an area suitable for agroforestry of 5.5 Mha in the Philippines (CHOKKALINGAM, 2006). FAY ET AL. (1998) estimated the area for potential conversion to agroforestry systems in tropical countries at 10.5 mn ha per year.

However, to date most CDM projects have been carried out in an industrial, waste management or fuel switch context. Forest-related projects have been planned, but elaborating proposals (Project Design Documents) requires an effort that appears deterrent even for commercial enterprises, who dispose of the necessary resources for such undertaking. For smallholders certain simplifications have been made[19], still with no measurable outcome in terms of actual A&R schemes[20].

Viability of agroforestry schemes for CDM has been economically evaluated in many case studies yielding different results and recommendations. Transaction costs play a major role in profitability of A&R projects and economies of scale are the most important determinant in the context, including costs relating to issues of establishing additionality and permanence, preventing leakage, and measuring carbon stocks within project sites (Yap 2003, Cacho et al. 2003).

May & Veiga (2007) calculated cash flow and return on investment over >20 years for different smallholder agroforestry systems[21] in Mato Grosso, Brazil, with participation by small and medium rural producers and their local associations. Results were favourable, even without CDM and improved significantly through CDM funds.

Agroforestry systems can be superior to other land uses at the farm, watershed, regional and global scale, because they optimize tradeoffs between increased food production, poverty alleviation, and environmental conservation (Izac & Sanchez, 2000, cited in IPCC 2001). Disabling policies and inappropriate technologies, however, can have disadvantageous and adverse effects (Sanchez 1995). Analysis of tradeoffs between private farmer benefits and global environmental benefits provide a basis for partitioning benefits arising from global environmental conventions and protocols. Figure 10 shows tradeoffs between carbon sequestration and farmer profitability in Cameroon across a range of practices (IPCC 2001).

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[19] So-called Small Scale Afforestation/Reforestation Projects (SSC A/R) with a sequestered net volume of <16.000 t CO_2/yr.

[20] updated information on implemented CDM projects under www.unfccc.org

[21] Including two systems of agriculture and tree species, incorporating coffee and palm tree cultivation. A third design integrated pasture with tree species and another one was a home garden.

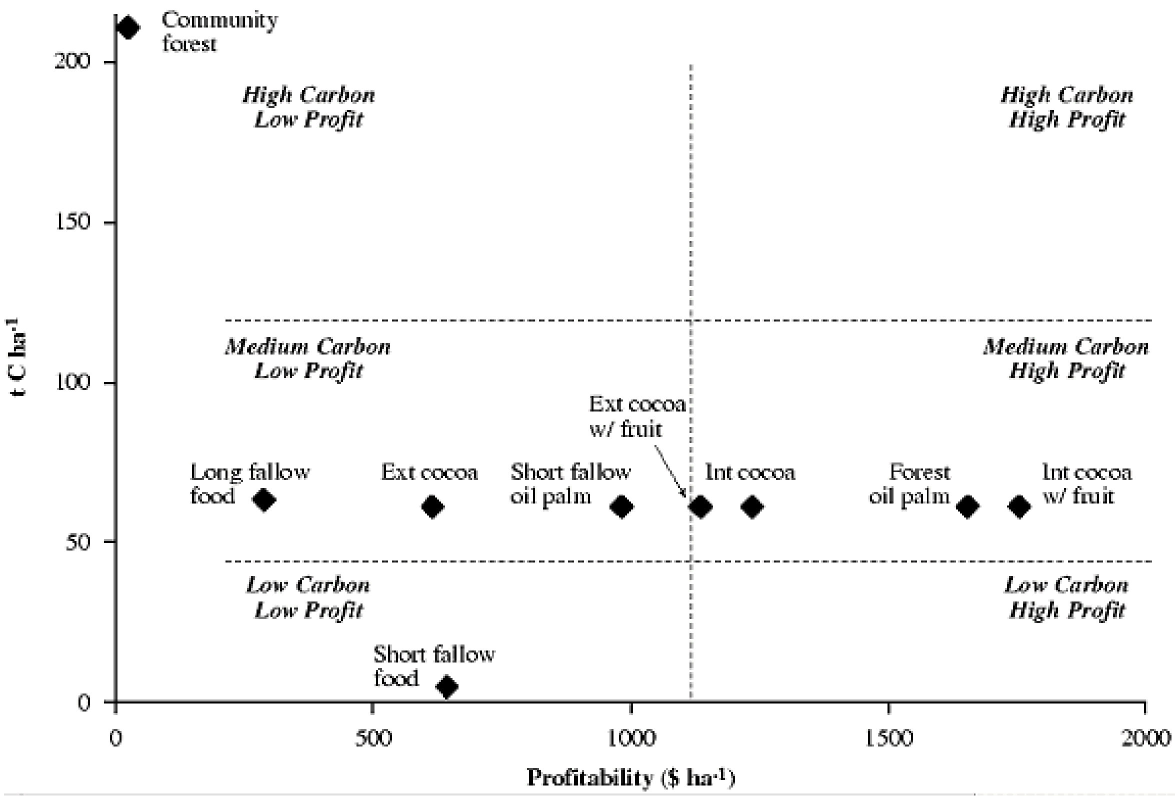

Figure 3: Tradeoffs between carbon stocks and social profitability of land-use systems in Cameroon (source IPCC 2001)

Despite the theoretical potential for CDM and other Payment for Environmental Services (PES) programs to benefit the rural poor, many current programs present serious obstacles to the inclusion of poor households. Obstacles identified in a Costa Rican case study include four major complexes (MOCK & WHITTEN 2005):

Tenure and formal titles: Secure property rights are one of the foundations of PES programs. Land ownership is almost always used to identify who should rightfully receive payments, a fact that excludes landless[22] poor farmers. Growing PES programs could even worsen the situation for the landless poor if demand in tenurial rights enforces competition.

Restrictions on land uses such as grazing may limit incomes, while at the same time payments alone are not sufficient to serve as a primary income source (VERISSIMO ET AL. 2002).

Transaction costs such as proposal writing, drawing up a contract and monitoring can become a burden on poor families (MIRANDA ET AL. 2003). Calculations of CDM profitability by SCHLAMADINGER ET AL. (2006) indicated that at given present credit prices and project-size limitation, high fixed transaction costs, short crediting periods and failure risks, net incomes are limited to a range of -5 to 9 USD/ha/a. Comparing these revenues with opportunity cost prospects for Small Scale A/R projects for poor communities are very limited. To a certain extent, organisation into associations supported by institutions can improve the prospects for successful CDM registration, but small size landholding still requires many participating households and thus strong institutional efforts in terms of time and funds to implement the adoption of the required land-use changes and practices (GINOGA ET AL. 2002).

[22] Or such with customary land rights.

Lack of credit and start-up funds. Changing farming, reforesting and other land-use practices to comply with PES requirements often involves significant investment in planting materials or training. In addition, lost income during the transition period has to be compensated or pre-financed, which is difficult for poor families, who typically lack credit and cash savings (Pagiola et al. 2003).

Despite the obstacles mentioned, PES programs can deliver important benefits to low-income participants such as increase of social cohesion through cooperative training and work, change of attitude, socialisation of generated knowledge or organisational and financing improvements and innovations (Bonilla 2007).

PES alone are not likely to allow poor families to escape poverty, but they could become an important contributor to livelihood security due to the regularity of the payments and the incentive they provide to manage resources sustainably.

Apart from carbon sequestration, which becomes effective in a mid-term after planting, agroforestry as all systems with high standing biomass have the potential to offset immediate greenhouse gas emissions associated with deforestation and subsequent shifting cultivation. This is the idea behind REDD (Reduced Emissions from Deforestation and Degradation), a relatively new climate-related funding scheme under discussion in the relevant gremia.

5.4 Macroeconomic role

Agroforestry products, in particular tree crops, which are often cultivated in agroforstry schemes, account for a significant share of total agricultural exports in many countries: In Côte d'Ivoire they made up for 35%, in Ethiopia 26%, in Ghana 25%, and in Kenya 23%, while in Uganda they accounted for 53% of all agricultural exports in the first decade of the 21st century. In Uganda, increased earnings from coffee exports largely contributed to a remarkable reduction in rural poverty. The total value of tree crop exports for Africa amounted to almost US$5bn in 2000 (World Bank 2002 cit. in Omont & Nicola 2006), including around US$1.5bn for Côte d'Ivoire and US$640mn each for Ghana and Kenya.

5.5 Total economic value

One of the factors that contribute to the degradation of natural resources is either undervaluation or absence of valuation of products and services in the livelihood system of rural households. Valuing these products and services provides information for decision-making concerning natural resources.

Table 2 gives orders of magnitude of different benefits emanating from tropical forests, which gives an idea of comparable values for agroforestry. Markets exist only for a fraction of these goods.

Table 1: Summary of economic values of tropical forests as calculated by P*EARCE* & P*EARCE* *(2001) in [$ ha/pa] 2 - Annuitised NPV at 10% for illustration. 4 - Assuming that compensation for carbon is a one off payment in the initial period and hence is treated as a present value. It is a gross value since no costs are deducted.*

Forest good or service	Tropical forests	Temperate forests
Timber conventional logging sustainable conventional logging sustainable	 200-4400 (NPV)[1] 300-2660 (NPV)[1] 20- 440[2] 30- 266[2]	 -4000 to + 700 (NPV)[3]
Fuelwood	40	-
NTFPs	0- 100	small
Genetic information	0-3000	-
Recreation	2- 470 (general) 750 (forests near towns) 1000 (unique forests)	80
Watershed benefits	15- 850	- 10 to +50
Climate benefits	360- 2200 (GPV)[4]	90 - 400 (afforestation)
Biodiversity (other than genetics)	?	?
Amenity	-	small
Non-use values Option values Existence values	 n.a. 2- 12 4400 (unique areas)	 70? 12 - 45

Perceiving agroforestry in this context not only as land use but as ecosystems that provide market and non-market goods, the Total Economic Value (TEV) may be considered as the most widely used framework to identify and quantify the contribution and values of ecosystem services to human well being.

According to the TEV model, ecosystems have both use values and non-use values. BABULO ET AL. (2006) further classify these values into four broad categories:

- Direct use values arising from consumptive and non-consumptive uses of the system, e.g. crops, timber and fuel, extraction of genetic material, tourism.
- Indirect use values accruing from environmental services such as protection of watersheds and the storage of carbon.
- Option values reflecting a willingness to pay to conserve the option of making use of the system even though no current use is made of it.
- Non-use values (also known as existence or passive use values) representing a willingness to pay for the system in a conserved or sustainable use state, whereas the willingness to pay is not related to the current or a planned use of the system.

The assessment of the TEV requires primarily a careful identification of various functions and uses as well as appropriate and credible valuation methods to capture their economic values. Generally, valuations are based on cost and benefit analysis.

Additional methods used in economic valuation are market prices, replacement cost and preventive expenditure, proxy/substitute products, opportunity cost, travel cost, hedonic pricing, and contingent valuation (KUSUMA 2005). BABULO ET AL. (2006) present a set of evaluation methods, which includes the market prices method, the efficiency (shadow) price method, the production function method, the related/substitute good method and the cost based method.

To date TEV- and especially non-markets value assessments have extensively been carried out for forest ecosystems, whereas related studies for agroforestry as land-use alternative to forest-to-agriculture conversion are scarce.

KUSUMA (2005) estimated the TEV of the natural resource management of a Kalimantan forest tribe (Indonesia) at 6,026 USD per hectare and year with direct use value of 0.028 USD per hectare per year (NTFP), an indirect use value of 3,156 USD per hectare per year, and non-use value of 2,870 USD per hectare and year.

Table 3 illustrates the difference in TEV under deforestation and conservation at the Leuser National Park in Aceh, Sumatra, Indonesia. It becomes clear that though forestry and agriculture-related products increase in NPV, the total NPV in the deforestation scenario is 37% less than in the conservation scenario.

Table 1: Distribution of benefits under deforestation and conservation at the Leuser National Park in Aceh, Sumatra (EFTEC 2005)

	Deforestation		Conservation	
	Value ($ million)	Percentage of total value	Value ($ million)	Percentage of total value
Water supply	699	10	2,419	25
Fisheries	557	8	659	7
Flood prevention	1,223	18	1,591	17
Agriculture	2,499	36	1,642	17
Hydro-power	252	4	898	9
Tourism	171	2	828	9
Biodiversity	56	1	492	5
Carbon sequestration	53	1	200	2
Fire prevention	30	0	715	7
NTFP	235	3	94	1
Timber	1,184	17	0	0
Total	6,958	100	9,538	100

The examples show how values vary by location so that even summary values in table 3 are only approximate indicators of the kinds of values that could be relevant.

PEARCE (2001) quantified the likely costs and benefits of converting different types of existing forests to alternative uses (table 4). Even though the BC-calculation is based on very limited data, general tendencies can be deducted.

Table 2: Costs and benefits of changing forest land use $/ha/a (- shows losses, + shows gains; PEARCE & PEARCE 2001)

Alternative land use → **Original land use ↓**	**Nutrient cycle: Logs, crops, ranching**	**Conventional logging**	**Agroforestry**
Primary forest	-223 to -3630 172 to 209	-150 to -3000 20 to 1440	-2 to -470 135 to 317
Secondary forest	-121 to -1050 172 to 209	-83 to -600 10 to 220	0 135 to 317
Open forest	-50	n.a.	135 to 317

According to the projections in table 4, costs of forest conversion into agroforestry fall below those of usual logging-cropping cycles or conventional logging practices, while benefits remain in a comparable range.

6 Coverage in tropical and subtropical developing countries

NAIR (1993) classifies tropical agroforestry systems in the tropics into three agroecological zones:

- Humid Lowlands with shifting cultivation, taungya, plantation-crop combinations, intercropping systems and multilayer tree gardens
- Semiarid lowlands with silvopastoral systems, windbreaks and shelterbelts, multipurpose trees for fuel / fodder and multipurpose trees on farmlands
- Highlands with soil conservation hedges, silvopastoral combinations, plantation-crop combinations

In 1996, the worldwide area in agroforestry was estimated at 400mn ha, of which 300mn were classified as arable land and 100mn as forest lands according to FAO databases. The potential land area suitable for agroforestry in Africa, Asia, and the Americas has been estimated at 585-1215mn ha (DIXON 1996). The greatest potential for expansion of agroforestry has been identified in degraded areas at the margins of the humid tropics. These areas make up for 250mn ha or 42% of the total deforested area of the humid tropics. It is assumed that 3 percent of these lands (7.5mn ha) plus 20 percent of the 15mn ha annually deforested areas (3mn ha) – a total of 10.5mn ha – could be converted into agroforestry annually under enabling government policies (WATSON ET AL. 2000).

Systematic data on extension of agroforestry are sparse and, given the different definitions of the term, statistics vary considerably between sources. For comparability, data presented in this section have been compiled from a centralised source, namely FAO land use data bases (HALL 2001). For each region, a map showing predominant land use systems over greater areas. Tree-based land use systems are then described to more detail in the respective table following each map. Area figures include the entire area potentially dominated by a given land use and the area actually cultivated under this land use. Key products and comments on extension or peculiarities of the system complete the tables.

6.1 Africa

The Middle East and North Africa are not treated here in detail as the FAO data base does not provide detailed data. However, irrigated areas mainly around Nile, Euphrat and Tigris (8.1mn ha) include tree crops and fruits. In rainfed mixed systems in the coastal Maghreb (about 2mn ha cultivated land), olives, fruit and grapes are grown, apart from annual crops like wheat, barley, chickpeas, lentils, fodder and melons.

Sub-Saharan African farming systems are categorised in figure 11 (source FAO land use data base) and include one explicit class of tree crop systems.

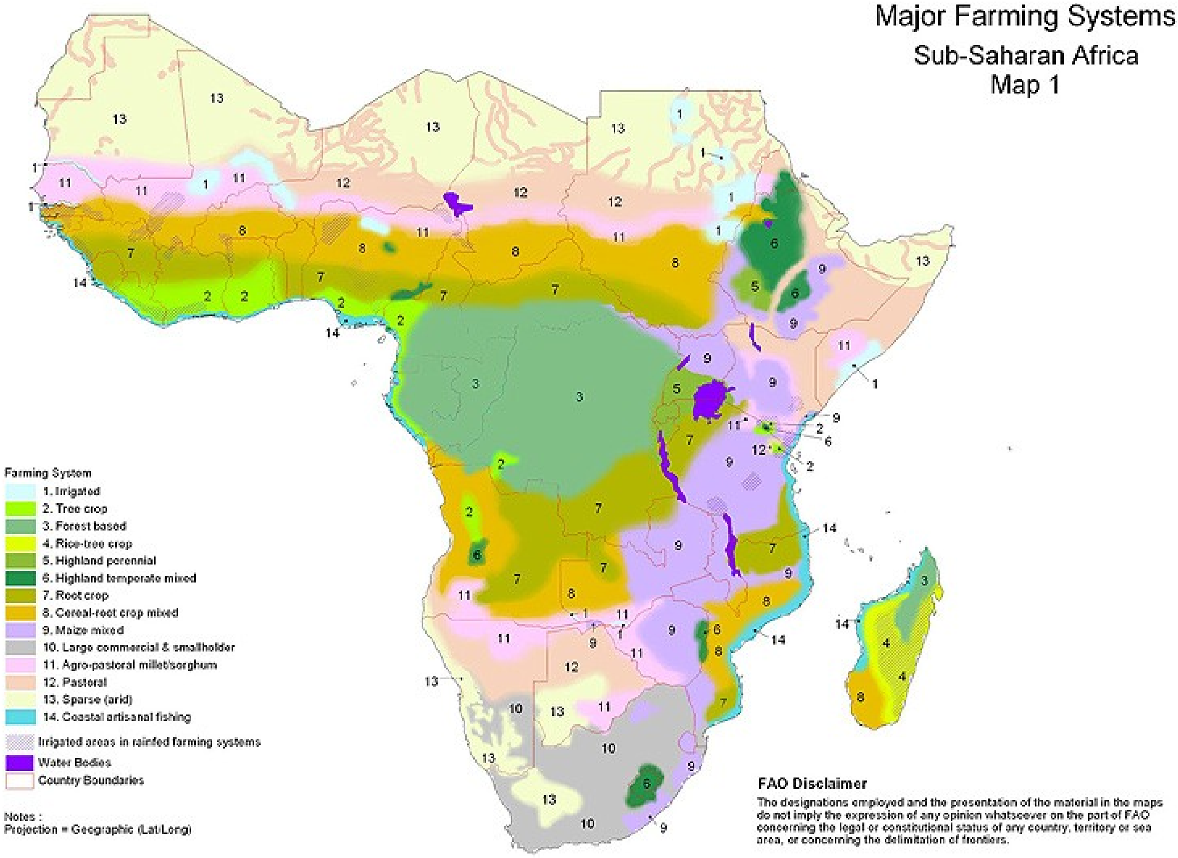

Figure 1: Major farming systems in Sub-Saharan Africa (FAO, source HALL 2001)

All systems containing agroforestry elements are presented to more detail in the following table 5., with area containing the entire area dominated by a farming system, while cultivated land is presented apart. Pastoralist systems in arid regions have not been taken up into the selection as trees in these systems are usually not planted.

Table 1: Tree-based agricultural systems in Sub-Saharan Africa (extracted from HALL 2001)

System	Area	Key products	Comments
Tree Crop Farming System	73mn ha, 10 cultivated	Cocoa, robusta coffee, oil palm and rubber; cassava, yam, cocoyam.	Humid zones: Côte d'Ivoire to Ghana, Nigeria to Gabon, pockets in Congo and Angola. Livestock limited by tsetse; fish farming in some areas.
Forest Based Farming System	263mn ha, 6 cultivated	Cassava, maize, sorghum, groundnut, beans, cocoyams	Central African forest zone. 2-5 years cultivation followed by 7-20 years fallow
Rice-Tree Crop Farming System	31mn ha, 2.2 cultivated	Banana, coffee, rice, maize, cassava, legumes	Madagascar
Highland Perennial Farming System	32mn ha, 6 cultivated	Banana, plantain, enset, coffee, cassava, sweet potato, beans, cereals; cattle	Inland East Africa; densely populated, 50% of farms <0.5ha
Cereal-Root Crop Mixed Farming System	312mn ha, 31 cultivated	Maize, sorghum, millet, cassava, yams, other, mostly intercropped.	W-E belt from Guinea-N Cameroon; Central and Southern Africa. Intercropping rather than agroforestry.
Maize Mixed Farming System	246mn ha, 32 cultivated	Maize, cattle, small ruminants, tobacco, coffee and cotton	East and Central Africa 800-1500m asl.
Coastal Artisanal Fishing Farming System	38mn ha, 5 cultivated	Crop production, multi-storied tree crop gardens (root crops, coconuts, fruit trees, cashew, animal production)	From Gambia to Gabun in the West and Kenya to Madagascar on the Eastern coast; densely populated

Tree crops play an important role for export in large parts of Africa. The principal agricultural exports are cocoa, coffee and cotton. Cocoa accounted for 48 and 22% of agricultural exports in West and Central Africa and coffee for 12 and 25% in West Africa and East Africa, respectively. Fruit production rose at an average annual 1.6% from 1970-2000 to 47mn tons harvested on 8mn ha. In Southern Africa, fruits and grapes are important perennial crops.

General problems in Sub-Saharan agriculture are HIV/AIDS, population growth and climate change (especially in arid areas). Main constraints for the tree crop systems in Sub-Saharan Africa are economic, namely price fluctuations, inputs and marketing. Strategies to improve the situation are related to these constraints, but also comprise quality of plant material, processing, product quality, diversification to reduce vulnerability to world price fluctuations. Credit schemes and farmer associations are further suggestions made by FAO.

Despite forests covering approximately 400 million ha (almost 17 percent of the land area), deforestation and the decline in forest area are continuing at the same pace as cultivated land increases. Shortened fallows, forest and grassland conversion into cultivated land are major tendencies that are often connected to soil erosion, compaction, reduced soil organic matter and declining soil fertility. Agroforestry is explicitly mentioned by the FAO as one strategy to achieve good soil management, i.e. mainly restoration of soil organic matter. On the other hand, farming systems most closely linked with deforestation are the forest based, but also tree crop systems. Fuelwood shortages are problematic in areas dominated by the maize mixed, highland perennial and highland temperate mixed systems.

6.2 South Asia

Trees play a major role in the dry central areas of India, mainly for fruit production and in conjunction with livestock. Explicit tree crop systems are dispersed and not shown in the FAO map (fig. 12); this includes e.g. tea plantations in the North of India. Note that estate crops are not necessarily agroforestry systems.

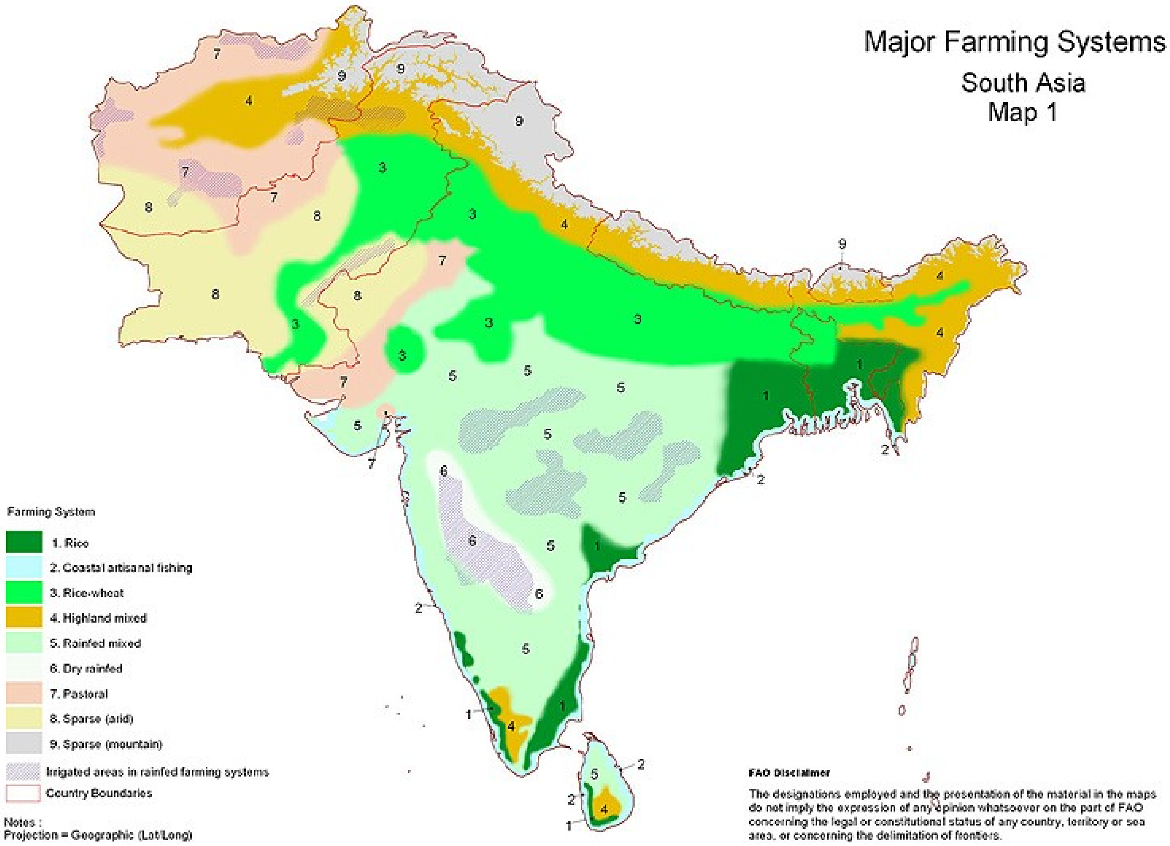

Figure 1: Major farming systems in South Asia (FAO, source Hall 2001)

Tree-based farming systems are presented in table 6. Sparse natural vegetation in arid areas is partly considered under dry rainfed systems.

Table 1: Tree-based agricultural systems in South Asia (extracted from Hall 2001)

System	Area	Key products	Comments
Highland Mixed Farming System	65mn ha, 19 cultivated, 2.6 irrigated	Cereals, legumes, tubers, vegetables, fodder (trees), orchards and livestock	Northern India to Bangladesh
Dry Rainfed and Rainfed Mixed Farming System	165mn ha, 97 cultivated	Rice, wheat, pearl millet, sorghum, pulses, oilseeds, sugarcane, vegetables and fruit	Central and South India, Sri Lanka
Tree Crop Farming System	3mn ha, 1.2 cultivated	Tea, rubber, coconut, other	Plantations and smallholders; N India, Sri Lanka, Kerala

Main challenges in the agricultural sector are seen in water management and diversification is mentioned as strategy to cope with water shortages. Other constraints are of organisational and infrastructural nature.

6.3 East Asia – Pacific region

Following the FAO grouping (fig. 13), temperate areas in China and Mongolia have been included in the description.

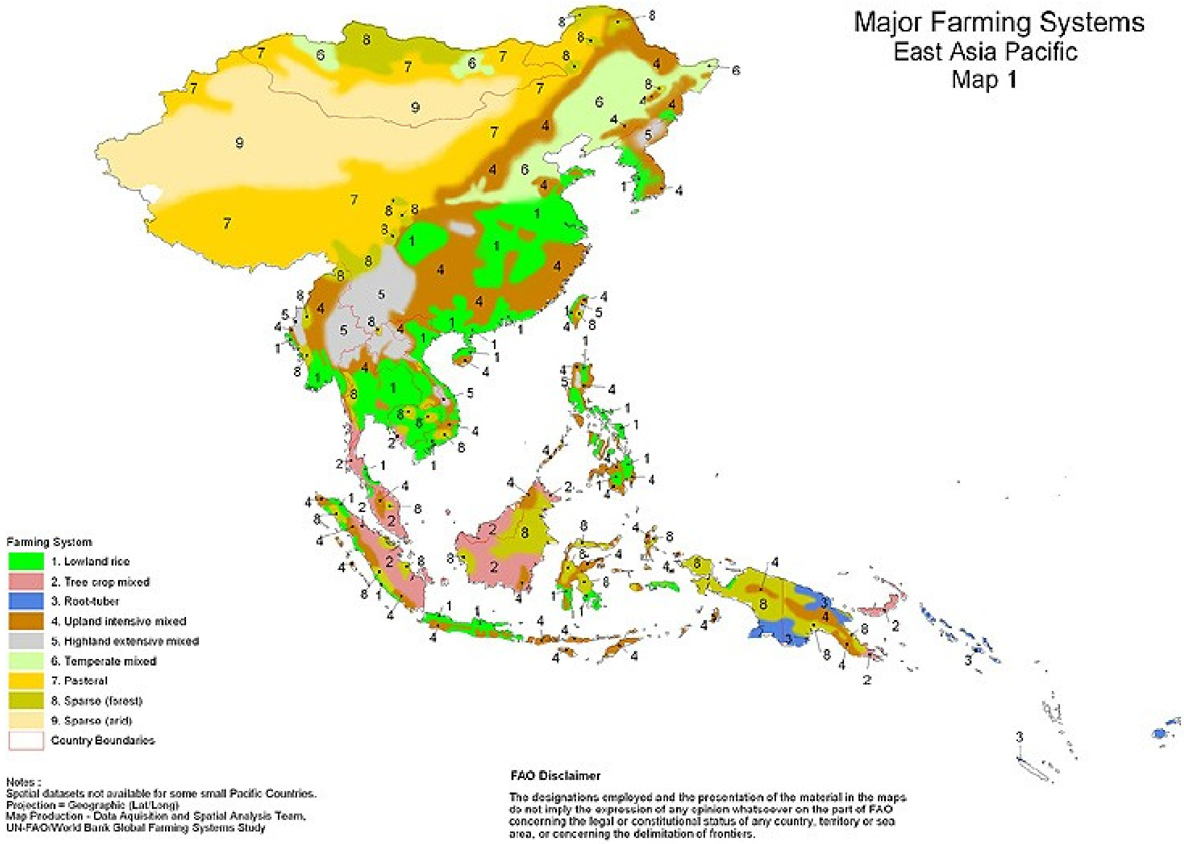

Figure 1: Major farming systems in East Asia and the Pacific (FAO, source HALL 2001)

A selection of tree-based farming systems is shown in table 7. So-called sparse (forest) farming systems, i.e. forest dwellers living on cultivation of annuals, livestock, hunting and gathering have not been included as trees are not deliberately planted (the agroecological zone comprises 172mn ha, out of which 10mn ha are cultivated).

Table 1: Tree-based agricultural systems in the East Asia – Pacific region (extracted from HALL 2001)

System	Area	Key products	Comments
Tree Crop Mixed Farming System	85mn ha, 18 cultivated, 12 irrigated	Rubber, oil palm, coconut, coffee, tea, cocoa, some pepper and other spices	Malaysia, Indonesia, Thailand, Cambodia, Philippines, Vietnam, S China, Papua New Guinea
Root-Tuber Farming System	25mn ha, 1.2 cultivated	Tubers (yams, taro, sweet potato), vegetables, fruits, banana, coconut; livestock, hunting and gathering in the forest	Papua New Guinea and the Pacific Islands
Upland Intensive Mixed Farming System	314mn ha, 75 cultivated, approx. 18 irrigated	Rice, pulses, maize, sugarcane, oil seeds, fruits, vegetables, livestock	All areas
Highland Extensive Mixed Farming System	89mn ha, 8 cultivated	Crops (including perennial crops such as fruit trees), livestock and forest products	Upland areas in Laos, Central and N Vietnam, N Thailand, N and E Myanmar, SW China, the Philippines, parts of Indonesia
Temperate Mixed Farming System	99mn ha, 31 cultivated, about 10 irrigated	Wheat, maize, some rice, cotton, soybeans, sweet potato, rape, citrus, temperate fruits; livestock	Central and N China, Mongolia
Pastoral Farming System	321mn ha, 12 cultivated, 2 irrigated	Transhumant pastoralism; irrigated cotton, barley, wheat, pulses, peas, broad beans, potatoes, grapes, sericulture (mulberry for silk)	Semiarid and arid temperate areas
Sparse (Forest) Farming System	172mn ha, 10 cultivated	Potato, buckwheat, cattle, yak in temperate regions, rice, root crops, ruminants, hunting, gathering in tropical forests	W China, N Myanmar, N Mongolia, Indonesia, Papua New Guinea
Coastal Artisanal Fishing Farming System	38mn ha	Rice, root crops, coconut, livestock	Coastal areas

Trees often planted on paddy bunds are not considered in the lowland rice systems.

6.4 China

China has a long history of agroforestry and several large-scale afforestation and agroforestry projects have been carried out, often with the purpose to reduce wind erosion in Northern China (shelter belts), combined with pasture. One example is the 'Green Great Wall' programme, which was begun in 1978 and covers 6.7 million ha of farmland and 3.4 million ha of pastures. Other shelter belts stretch over 440,000 ha in the Ningxia Hui and Inner Mongolia Autonomous Regions; and 600,000 ha in the Xinjiang Uygur Autonomous Region.

Main agroforestry activities in the central plains include farmland shelter belt and forest networks and planting trees around houses, along roadside and river banks etc. Several systems of intercropping agricultural crops with trees have also been implemented in the plains, which cover more than 2mn ha. The main forms of intercrop are agricultural crops with *Paulownia* (1.3mn ha), date, fruit trees, willow, false indigo and white mulberry. Main purposes are control of wind erosion, use as organic fertiliser or fodder and income from fruits.

In the provinces of Hebei, Shandong, Henan, Anhui, Shanxi and Jiangsu, by 1987 so-called farmland forest networks covered 11.2mn ha or 48.5% of total farmland. Intercropping of crops with *Paulownia* trees amounted to 3.26 million ha or 59.1% of the provinces' arable lands (Maogong 1997).

Annually an average of 3 million ha of land is afforested in China (Maogong 1997). Time series of several tree-based systems (mainly tea, mulberry, apple, citrus, pear, grape, and banana) are presented in table 8.

Table 2: Area under tree-based land uses in China. Yuchuan (1998)

Year	**Area / increase**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**
Orchard	$10^3 km^2$	2736	3672	4508	5066	5372	5179	5318	5818	6432	7264	8098
	%	+23.7	+34.7	+22.8	+12.4	+6.0	-3.6	+2.7	+9.4	+10.5	+12.9	+11.5
Mulberry	$10^3 km^2$	413	361	338	345	383	484	726	841			
	%	+0.5	-12.6	-6.4	+2.1	+11.1	+26.4	+50.0	+15.7			
Tea plantation	$10^3 km^2$	1045	1024	1044	1056	1065	1061	1060	1084	1171	1135	1115
	%	-3.0	-2.0	+2.0	+1.1	+0.9	-0.1	-0.1	+2.3	+8.0	-3.1	-1.7
Garden	$10^3 km^2$	4773	5676	6560	7161	7515	7406	7801	8430			
	%	+12.3	+18.9	+15.6	+9.2	+4.9	-1.4	+5.3	+8.1			

Recently, rubber plantations are increasing in some regions such as Southern China and Vietnam. While jungle rubber on peat soils in Sumatra is considered a system relatively close to nature, doubts have been expressed towards sustainability of these new large scale plantations.

6.5 Latin America and the Caribbean

The subcontinent stretches over a wide range of latitudes and (eco)systems are difficult to summarise; the subclasses of different Andean agroecological zones and farming systems in fig. 14 are owed to this N-S extension.

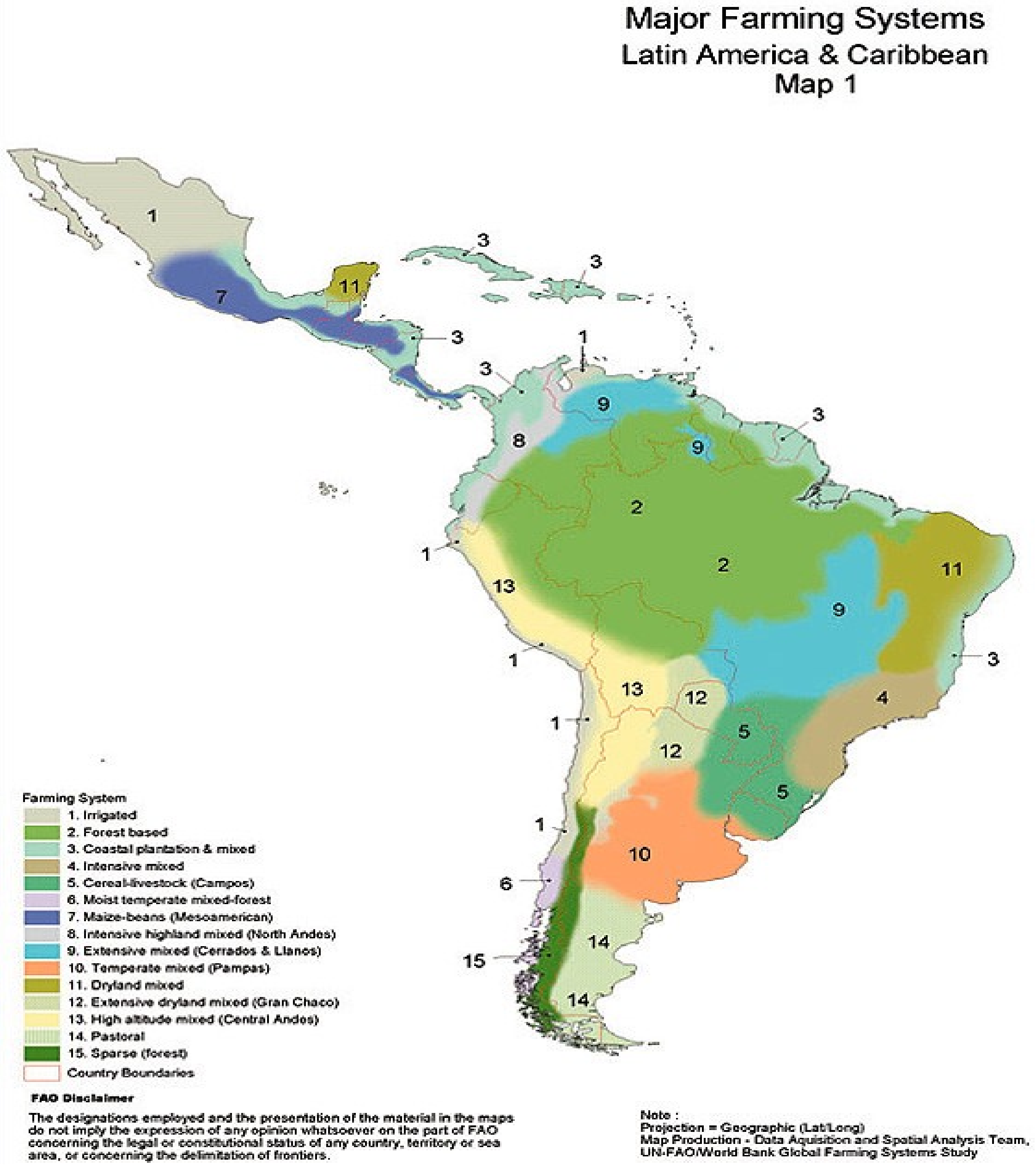

Figure 1: Major farming systems in Latin America and the Caribbean (FAO, source HALL 2001)

Selected tree-based farming systems are explained in table 9.

Table 1: Tree-based agricultural systems in Latin America and the Caribbean (extracted from HALL 2001)

System	Area	Key products	Comments
Irrigated Farming System	Almost 7.5 mn ha	Rice, cotton, fruit, horticulture and vines	High degree of intensification of production - generally commercially oriented
Forest Based Farming System	600mn ha, <1% cultivated	Subsistence, beef, plantation	Low-input settler agricultural activity, interspersed with extensive beef and plantation
Coastal Plantation and Mixed Farming System	186mn ha, 20 cultivated, 13 irrigated	Diverse	Small-scale family farms with mixed agriculture; large-scale export-oriented plantations
Intensive Mixed Farming System	81mn ha, 13 cultivated	Coffee, horticulture and fruit	Central Brazil
Dryland Mixed Farming System	130mn ha, 18 cultivated, 0.4 irrigated	Maize, rice, cassava, natural cerrado vegetation, milpa (maize, beans, squash and bush fallow)	NE Brazil, Yucatán
Moist Temperate Mixed-Forest Farming System	13mn ha, 1.6 cultivated	Natural and plantation forest interspersed with dairy, sheep and crops such as sugar beet, wheat and barley	Temperate ecosystems in coastal Chile
Intensive Highlands Mixed Farming System	43mn ha, 4.4mn cultivated	Lower altitudes: Coffee and horticulture; highlands and upper valleys: Temperate crops, maize and pigs	Northern Andes
Sparse (Forest) Farming System	200mn ha, 1mn used	Livestock grazing, forestry	Southern Andes

Increase in fruit production as indicator for tree crops was at 2.8% annually between 1970 and 2000, reaching 99mn t harvested on 7mn ha in 2000.

FAO recommendations for the entire region in the category of resource management read like an agroforestry manual: *'Dissemination of proven technologies for smallholders, notably green mulching, small-scale no-till, vegetative barriers, terracing and zero grazing; expanded attention to the selection, testing and dissemination of varieties appropriate for small producers, with an emphasis on permanent and tree crops; financing producer out-migration from unsustainable lands to permit reforestation.*' Priorities identified for drylands focus on resource rehabilitation through legume soil cover (*Mucuna sp*. and *Canavalia sp*. are recommended), limited grazing and intensified valorisation of the natural vegetation.

7 Key actors

The list of actors in this section is not comprehensive. Especially in the NGO sector, innumerable groups exist that pursue agroforestry goals at least in some of their projects. Also, there are many national R&D institutions in developing countries and university institutes worldwide focusing on agroforestry. The list contains a only selection of institutions.

Institution	Description	Programs / Activities
International Research		
World Agroforestry Centre (ICRAF) www.worldagroforestry.org	Key actor in agroforestry research. CGIAR (Consultative Group on International Agricultural Research) supported 'Future Harvest Centre'.	Currently 14 research and R&D programs mainly focusing on Africa and South-East Asia. Future Research areas: • Domestication, utilization and conservation of superior agroforestry germplasm. • Maximizing on-farm productivity of trees and agroforestry systems. • Improving tree product marketing for smallholders. • Reducing risks to land health and targeting agroforestry interventions to enhance land productivity. • Improving the ability of farmers, ecosystems and governments to cope with climate change. • Developing policies and incentives for multifunctional landscapes with trees that provide environmental services.
Bioversity International www.bioversityinternational.org	Dedicated to the conservation and use of agricultural biodiversity. CGIAR-supported 'Future Harvest Centre' with the objective to make optimal use of agricultural biodiversity to meet current and future development needs of people and societies.	15 projects in 100 countries; four Programmes and three Research and Support Units (RSU): • Programme on Diversity for Livelihoods • Programme on Understanding and Managing Biodiversity • Programme on Improving Livelihoods in Commodity Based Systems • Programme on Global Partnerships • Policy and Law RSU • Capacity Development RSU • Public Awareness RSU
Centre for International Forestry Research (CIFOR) www.cifor.cgiar.org	Internationally relevant forestry research for poverty alleviation and environmental protection. CGIAR-supported 'Future Harvest Centre'.	Forest-related research with some overlap to agroforestry topics. Joint activities with the World Agroforestry Centre (ICRAF), e.g. the CIFOR-ICRAF Biodiversity Platform on biodiversity issues in multifunctional landscape mosaics. Priority research domains: • Enhancing the role of forests in climate mitigation. • Enhancing the role of forests in adaptation

		to climate change. • Improving livelihoods through smallholder and community forestry. • Managing tradeoffs between conservation and development at landscape scale. • Managing impacts of globalised trade and investment on forests and forest communities. • Sustainable management of tropical production forests.
International Center for Tropical Agriculture (CIAT) http://www.ciat.cgiar.org	Dedicated to reducing poverty and hunger while protecting natural resources in developing countries. CGIAR-supported 'Future Harvest Centre' Objectives: Competitive agriculture; healthy agroecosystems, rural innovation	Diverse project portfolio around three initiatives: • Sharing the Benefits of Agrobiodiversity, • People and Agroecosystems in the Tropics, and • The Tropical Soil Biology and Fertility (TSBF) Institute.
The Center for Subtropical Agroforestry (CSTAF) http://cstaf.ifas.ufl.edu/	Multidisciplinary, multi-institutional centre established at the School of Forest Resources and Conservation (SFRC), University of Florida	Research, extension, and education and training related to agroforestry.
International Development		
Food and Agriculture Organization of the United Nations (FAO) www.fao.org	Provides information and expertise to modernize and improve agriculture, forestry and fisheries practices and ensure good nutrition for developing and transition countries.	Agroforestry-related issues are addressed by both the Agriculture and the Forestry departments' programmes: • Properties and management of drylands (Agriculture Department, Land and Water Development Division). • Promotion and Development of Non-wood Forest Products (NWFP) for sustainable utilization of NWFP, biodiversity conservation, income-generation and food security. • Global Forest Resources Assessments, providing a holistic perspective on global forest resources, their management and uses.
Asia Pacific Agroforestry Network (APAN)	FAO programme to facilitate collaborative agroforestry activities in the region	

Technical Center for Agricultural and Rural Cooperation (CTA) www.cta.int/index.htm	ACP-EU institution working in the field of information for development and operating under the ACP-EU Cotonou Agreement.	Three major programmes: • Increasing the availability of agricultural and rural development information and the awareness of information sources, • Promoting the integrated used of communication channels and greater exchange of information, • Improving the capacity to generate and manage information and to formulate information and communication management (ICM) strategies.
Regional and National Research and Development Institutions		
Tropical Agricultural Research and Higher Education Centre (CATIE) www.catie.ac.cr	Promotes competitive and sustainable agriculture and natural resource management, through higher education, research and technical cooperation Regional Focus: Central / Latin America	Priority areas 2003-2013 (CATIE 2003) • Research Programme : Sustainable rural development, enhancing competitiveness, added value to products, expanding the range of analytical tools for decision making. • Education Programme • Outreach Programme, participative research, training, dissemination of knowledge and technologies, policy advocacy, field validation of new technologies, institutional strengthening at national and regional levels.
Embrapa www.embrapa.br	National agricultural research institution in Brazil	Focus on agroforestry especially in regional research stations in Belém and Manaus (former SHIFT project)
INPA, Instituto Nacional de Pesquisas da Amazônia, Manaus, Brazil www.inpa.gov.br	Institute of Amazon Studies	Several research projects on agrobiodiversity, resource use in agricultural and forest-based systems
INIA, Instituto Nacional de Investigación Agrária del Perú http://www.inia.gob.pe/	National agricultural research institution in Peru	Focus on agroforestry especially in regional research stations in Tarapoto, Iquitos and Pucallpa
Philippine Council for Agriculture, Forestry and Natural Resources Research and Development (PCARDD)	National agency under the Department of Science and Technology	Agro Forestry Information Network(AFIN)[23]: Platform for the dissemination of knowledge and information on agroforestry technologies and R&D activities.
DED Brasil http://brasil.ded.de/	German government development agency with participatory approach	Agroforestry groups in Bolivia and Brazil are closely linked. Focus implementation of sistemas multi estrato with smallholders and dissemination of the related techniques
DED Bolivia http://bolivia.ded.de		

[23] www.pcarrd.dost.gov.ph/cin/AFIN/AGROFORESTRY%20INFORMATION%20NETWORK %20(AFIN).htm

Non Governmental Organisations (NGO)		
Centre for Agricultural Bioscience International (CABI) www.cabi.org/home.asp	Publisher	Provides scientific expertise, scientific knowledge and information in support of sustainable development, with emphasis on agriculture, forestry, human health and the management of natural resources.
International Analog Forestry Network (IAFN) www.analogforestrynetwork.org	R&D-Platform for information and knowledge exchange between Analog Forestry System promoting and applying groups.	IAFN-RIFA conducts projects on (agro) biodiversity restoration with communities mainly in Central America and the Carribean
Permaculture www.permaculture.org	Worldwide network with centres in Australia and the USA	Focus on permacultural design training courses on site
agroforestry.net www.agroforestry.net	NGO based in Hawaii	Dedicated to providing information and educational resources about agroforestry, trees, and sustainable stewardship of land and water Regional Focus: Pacific Islands.
Agroforestería Ecológica www.agroforesteriaecologica.com	Internet platform based in Cali, Colombia	Dissemination of publications on agroforestry, exchange
Asociación de Agricultura Ecológica www.aae.edu.tc	Farmer network in Puerto Maldonado region, Peruvian Amazon.	Initial focus on cover crops for soil rehabilitation and weed control (machete verde), leguminous tree species.
Trees for the Future (TftF) www.treesftf.org	US-based NGO initiating and supporting agroforestry self-help projects in cooperation with groups and individuals in developing countries.	Currently running extensive tree-planting programmes in 13 developing countries of Africa, Asia and Latin America. In conjunction with these major projects, TfTF is working in various communities worldwide through distance agroforestry training and seed distribution programmes.
Centre for Information on Low External Input and Sustainable Agriculture (LEISA) www.leisa.info/	Global information and knowledge exchange platform	Publish success stories of small-scale farmers from all over the world to help improve productivity, generate income and empower farmers.

8 Restricting framing conditions

From the FAO recommendations on strategies in section 6 it has become clear that regional and even local settings are diverse and the importance of different constraints cannot be generalised. In consequence, the most common restrictions can be summarized but not ranked here.

8.1 Biophysical constraints

As shown, agroforesty systems are not restricted to predefined combinations of plants and thus are highly flexible. Design principles oriented in natural succession provide a framework that developed over millions of years.

As in any natural system, plants in agroforestry need light, water and nutrients. As lack of light in agroforestry is caused by shading through other elements in the system, it can be avoided by design (row spacing, canopy structure, and timing) and management practices (pruning, thinning). The same is true for destructors: Proper fencing may be necessary to keep out chicken, pigs, cattle or uninvited harvesters (s. fig. 15).

Figure 1: Shading (here under the dense canopy of mango trees in Lovina, Bali, Indonesia) and destructors (here chicken) have their impact on agroforestry systems. In this case belowground competition and weeding may have facilitated eradication of undergrowth.

Regarding water and nutrients, design can minimise competition and optimise resource use exploiting all niches (root zones and canopy), keeping nutrient cycles tight and nutrient mobilisation high. However, under marginal conditions and with no external inputs, spacing in the system will have to be adapted to resources. Figure 16 shows options of agroforestry systems along a gradient of water availability in Bali, Indonesia.

Figure 2: Agroforestry systems in Bali along a gradient of water availability, left to right: Rice systems under abundant water in Amed (valley on windward side of mountain), grape-tree-grass system under pronounced dry season in Seririt, maize-legume-cattle system in a semi-arid leeward climate (rain shade) in Amed.

Proper tree-site matching, i.e. selecting the most appropriate species for a site, is crucial along relief and temperate gradients, too. Fig. 17 shows combinations of plants along an altitudinal (and temperature) gradient near Seririt, Bali.

Figure 3: Lowland and highland agroforestry systems near Seririt, Bali. Left side coffee, cocoa, banana, avocado, cloves in the lower valley area; right citrus, cabbage, strawberry on an exposed mountain ridge approx. 300m higher. Horizontal distance between both systems is only a few kilometres.

Under these conditions, agroforestry is flexible and highly adaptable to meet challenges of climate change such as erratic rainfall or storms.

8.2 Financial resources and material inputs

Costs for agroforestry generally do not differ from such of monocropping or other systems. As agroforestry can be low or high input, a generalisation cannot be made, except for the statement that agroforestry due to the optimised resource use can be adapted to low input conditions more easily than monocropping systems.

Regarding planting material, it has been stated that availability of quality or high yielding material can be problematic in some places (v. Noordwijk et al. 2003). While such comments, when referring to tree germplasm, often use clones and quality material synonymously, it has been argued, that biodiversity cannot be narrowed to the aspect of interspecies diversity, but needs to consider the intraspecific gene pool as well. This is of special importance in conservation approaches like the Philippine rainforestation, where seeds of Dipterocarpaceae are collected in primary forests. In addition, producing large quantities of clones from a deficient mother plant can be problematic in the case of trees, where effects may appear only after several years.

8.3 Labour

All systems that ban burning for installation require substantial work force for clearing the site. Sometimes farmers may be reluctant towards this kind of field preparation, because they fear attacks of wasps, bees, snakes, ants or other animals.

Once installed, agroforestry systems have the potential to minimise labour inputs through natural regulation of weeds and pests/diseases. In addition, field preparation is not necessary anymore from the second year onward. Especially weed control is a major factor determining farmers' work load during the first year. Once the canopy closes, weeds are not problematic anymore, but before, weeding may be complicated by a complex design (weeding between rows without cutting the cultivar) or special practices as described for the multi estrato system.

Labour saving techniques have been proposed and successfully tested in several environments. Prominent examples are the 'machete verde'[24] (green machete) *Mucuna pruriens*, an aggressive vine sown into weeded fallows and guaba, *Inga spp.* a legume tree. Mucuna covers and suffocates all vegetation within one vegetation period while at the same time producing large amounts of biomass and fixing nitrogen from the atmosphere. It needs to be cut before reaching the generative phase. Guaba is used to shade out *Imperata spp*. and other grasses that form competitive dense root mats and outcompete most plants. Imperata fallows are often considered not recoverable. Guaba trees are sown in the grassland after 'plating', i.e. clearing a round patch of approx. 50cm diameter or covering it using a plastic collar surrounding the tree. During the establishment phase, the tree must be kept free from weed, but after about 6 months will start to shade the light demanding grass. *Inga spp*. are a multi purpose trees used as fruit, timber and fence posts.

Once a system is well-established, labour peaks can usually be better distributed or flattened than under monocropping systems. Sequential harvesting due to staggered maturity periods is one reason for this. Additionally, many plants especially in forest-like systems[25] can be harvested over a longer period, so that work loads can be distributed accordingly.

Bertomeu (2006) concluded from an evaluation of smallholder timber-based agroforestry systems (maize plus timber hedgerows) in the Philippines 'that farm forestry is a more attractive option [*than maize monocropping*] for labour and capital-constrained households or those with off-farm opportunities that compete with their labour. These farmers may raise productivity and income by establishing timber-based agroforestry systems on excess land that cannot be devoted to annual crops.'

8.4 Land tenure and farm size

As discussed, farm and plot size has a strong impact on the type of agroforestry system implemented, while land tenure affects adoption of tree-based systems *per*

[24] Term coined by Asociación de Agricultura Ecológica in Puerto Maldonado, Peru, who gathered considerable experience with this technique.

[25] For example rattan, honey, timber, certain medicinal plants and dyes, resins and latex etc.

se. In general, legalised land tenure is supposed to be *conditio sine qua non* for the successful implementation of tree-based systems. Apart, it has been stated that tenure leads to greater willingness to invest labour and other resources into land improvement/rehabilitation and to foment a longer term perspective (NORTON-GRIFFITH 2008).

An analysis carried out in Kenya found that secure private tenure acted as a strong incentive in adopting more sustainable land use practices. Tenure strongly improved the area-specific productivity and the economic performance (return to labour) and mitigated market distance effects. This also applied for agroforestry practices such as the adoption of hedgerows and cultivation of woody crops, which was clearly higher on private land than under customary tenure (see table 10).

Table 1: Tenure Effects: Economic and Environmental Indicators in Kenya (NORTON-GRIFFITH 2008)

Land Use	Private Tenure	Customary Tenure	Tenure Effect
Economic Indicators:			
Net returns to land ($/ha/yr)	$301.80	$ 83.00	**3.6**
Cash crops (ha/km2)	12.90	2.33	**5.5**
Livestock returns ($/ha/yr)	$25.20	$8.62	**2.9**
Managed pastures (ha/km2)	5.17	0.13	**39.8**
Environmental indicators:			
Total woody vegetation	24.33	22.32	**1.1**
Privately managed woody veg	11.45	3.01	**3.8**
Woody crops	4.31	0.24	**18.0**
Hedgerows (km/km2)	23.55	5.14	**4.6**
Woodlots	1.27	0.06	**21.2**

Various other studies suggest that the adoption for a certain land-use practice strongly depends on the land tenure status. A large scale survey carried out in agroforestry households in Haiti showed that the practices adopted depend on farm-family strategy, land tenure security and soil fertility (BANNISTER & NAIR 2003).

8.5 Infrastructure and marketing

Market distance and a lack of infrastructure on one hand can be a motivation for farmers to adopt certain agroforestry practices, which increase self-sustaining capacities. For instance, in the Philippines, distance from the farm to the market was a significant variable to explain in why farmers adopted contour hedgerows (PANDEY & LAPAR 1998, cited by THIEN 2003). On the other hand lacking infrastructure like roads, electricity, telephone in rural areas impede market access, information on prices and demand as well as opportunities for local value addition (e.g. processing).

It has been argued that in diversified systems a marketing strategy and channel needs to be developed for every single product, even if only small quantities are harvested at a time. Market chains for tradable commodities should be assessed before a certain plot design is determined. For this purpose market information must be considered in the process of project design and contacts to buyers (more lucrative than local middlemen) must be established at an early stage. Small-scale farmers often are poorly organized, lack business skills, supportive institutions and policies (e.g., credit, market information) as well as tools that would allow to exploit available opportunities, such as means for adding value to produce (ROSHETKO ET AL. 2007). Necessary steps may include founding farmers' associations: Due to lower harvested amounts per commodity and area, common storage and processing facilities may be necessary to quantitatively meet buyers demands, especially when distant markets are targeted. Examples are palm oil, which needs to be processed immediately, or commodities that need to be cooled.

Premium prices for agroforestry products cannot be easily realised as the farming system *per se* does not include common certification criteria such as organic, fair trade, regional or designation of origin. Minor labels like bird-friendly coffee grown under shade trees try to tap the premium sector. However, in most cases switching to certified organic appears most promising, at least for export commodities. To achieve this it is necessary to convince farmers that certification is necessary[26] and to convince buyers to pay more for certain products. Foreign-funded organisations often neglect domestic markets aiming at export markets, where willingness to pay for premium products is supposed to be higher. As projects in Peru showed, the urban market can be a good retail environment for organised small farmers once contacts and acceptance exist[27]. To achieve this, institutional support is indispensable for resource poor smallholders.

8.6 Governance

The impact of governance has been reviewed for many countries, exemplarily for the Philippines, where government programs and incentives as well as competing settlement projects significantly influenced reforestation projects (BUGAYONG 2004; CHOKKALINGAM ET AL. 2006; DARGANTES & KOCH 1994; KUMMER & TURNER 1994). Generally, two main obstacles can be identified:

- Land tenure rights can discourage agroforestry where planting trees is seen as setting a claim for entitlement of squatted land.
- Bureaucratic efforts like registering planted trees with natural resources authorities (in order to be allowed to cut them one day) is another demotivating moment.

Often, missing funding schemes are mentioned as a shortcoming for agroforestry implementation. This argument may be valid in parts, but it should be kept in mind, that missing long-term commitment of farmers may be veiled by (short-term) subsidies. In corrupt or highly regulated environments, bureaucratic hurdles can be critical for agroforestry implementation.

8.7 Knowledge and extension

Many of the pitfalls mentioned in the previous subsections can be avoided when information is available. Indigenous knowledge is an important source regarding species selection, tree-site matching, preferred uses and cultural acceptance. This includes the farmer to farmer approach, which generally requires external inputs for logistics and travel funds.

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[26] Often farmers equate organic and low input or smallholder agriculture and do not see the need for 'additional' labels and costs.

[27] This example refers to the establishment of farmers' markets for organic produce and to organic products taken up into the portfolio of a supermarket chain in Lima.

Extension can also play a crucial role when innovation, bridging of initial gaps in equipment, planting material or other costs are concerned. This is often the case in rural areas, where credit is not available. Empowerment of socially disadvantaged groups can be another important task of extension. In practice, women have often proved to be better caretakers for trees, which need continuous attention over several years. On the other hand, they are not always the household decision makers. In this case special efforts are needed, which address the appropriate target group, but without causing social turbulences.

A study by MATATA ET AL. (2008) found that farmers with higher extension contact are more likely to adopt agroforestry technologies. However, the provision of free seeds/seedlings and other equipment does not guarantee tree planting and maintenance. A compromise between development organisation and farmer (group) is needed *a priori*, which defines duties on both sides. Farmers should develop ownership, which is only possible, if they clearly see the benefit of the system. An indicator for this view can be that farmers are ready to shoulder part of the investments.

Extensionists should always consider the local settings, both biophysical as well as sociocultural. Enforcing a successful blue print to different local settings or being bound to predetermined mindsets (like Green Revolution or romantic ideas) will almost certainly lead to project failure.

Similarly to what has been stated in this section, V. NOORDWIJK ET AL. (2003) identified five major bottlenecks for the broad implementation of agroforestry:

- Terminology issues linked to the legal status of land, restricting access to land or the right to plant and benefit from trees,
- access to planting material of good quality and proven suitability for the site,
- management skills and know-how to produce tree products of the qualities recognized and appreciated in markets for tree products,
- overregulation of access to markets for farmer grown timber,
- lack of reward mechanisms for environmental services provided on farm.

In addition to these points, the potentially long time until first harvest may be deterrent for farmers, if the proposed agroforestry design does not foresee annuals and biennials that provide income during the initial period.

9 Areas of research and action

As leading research institution with a world mandate for agroforestry, the partly EU-funded World Agroforestry Centre categorizes its projects under the topics of productivity, livelihood, land use management and resource use efficiency, biodiversity, valorization and marketing, payment for environmental services (PES) and education. As an institution committed to research for development the Centre identified a number of challenges and opportunities for agroforestry (GARRITY ET AL. 2006).

Some of the key issues described above are addressed through the ICRAF 2008-2015 strategy presented in section 7 and focus on germplasm, productivity, marketing, adaptation to climate change and payments for environmental services on a landscape scale.

A more detailed list of goals and activities elaborated by the Word Agroforestry Centre in 2006 can be found in the Annex.

Within the World Agroforestry Centre, emphasis in the Southeast Asian regional centre is more on CDM and lately REDD related issues, while topics in Africa are more dominated by soil fertility issues. In Latin America, the centre is under-represented with only one office in Pucallpa, Peru. In Latinamerica, agroforestry is dominated by NGO, with focus often on participatory smallholder approaches, processing and marketing including certification efforts. A bias between perceived organic[28] and certified organic is often an obstacle to successfully targeting the premium market segment.

VERCHOT ET AL. (2007) identified major knowledge gaps in the field of climate change. For research as well as action, adaptation to climate change is the major issue: It is stated that "*climate shocks are a major source of setback for smallholder farmers and are a leading cause of farmers falling into poverty*", while agroforestry has the potential to mitigate the effects of climatic variation and extreme weather events. To quantify the potentials would be a first decisive step towards developing agroforestry-based strategies to reduce susceptibility and increase resilience. Another important research need is the role N_2O and CH_4 emissions from different systems.

Research focus at university level is often on biophysical resource use and competition. A former special research programme (SFB) West Africa at University of Hohenheim, the STORMA project in Indonesia, the SHIFT projects in Brasil contain important agroforestry components. For temperate regions, agroforestry research has been conducted within the SAFE (Silvoarable Agroforestry For Europe) project by a consortium around INRA, Montpellier. SAFE includes specific agroforestry computer models to predict plant growth and some economic parameters[29]. As agroforestry systems take time to grow and innumerable combinations of planting systems and site conditions are possible, modelling has become an indispensable tool for agroforestry research. Once a model is parametrised and calibrated to the respective site, scenarios can be run to explore different planting patterns and management options and their effects on yields, income or environmental parameters. Current tropical agroforestry research at the University of Hohenheim combines modelling approaches using WaNuLCAS,[30] FALLOW[31] and LUCIA[32] models to assess consequences of different land uses, agroforestry included, on

[28] Often used synonymously to ‚smallholder'.

[29] Namely Yield-SAFE for the biophysical and Farm-SAFE for the economic part.

natural resources and environmental functions like water storage, erosion and nutrient reallocation in the landscape, among others. These modelling exercises are usually accompanied by own field data collection as data transfer from others remains a critical point.

Socio-economic research on agroforestry is less widespread than biophysical themes. Dominant topics are comparisons between agroforestry and common practice land use regarding profitability. Models like SCUAF and WaNuLCAS include simple economic functions. A study comparing preferences between classical maize-based systems vs. improved fallow approaches in Kenya from a biophysical vs. an economic point of view using WaNuLCAS has recently been published by Chukwumah et al. (2008).

Socio-economic issues under research are cost-benefit calculations, biodiversity and environmental services provided by agroforestry, and stakeholders' often diverging interests in land use, e.g. agricultural use vs. conservation, where agroforestry may take an intermediate position (e.g. the ALAM project[33]).

In a meta analysis covering >500 publications on agroforestry from 1992-2002, Montambault & Alavalapati (2005) come to the conclusion, that economic, non-market and household benefits were the most researched topics, while macroeconomics, property rights and gender remained under-represented. Regarding systems, the focus shifted from forest-like to silvopastoral systems. All in all, the bulk of publications referred to tropical agroforestry with temperate systems making up for less than a third of all publications.

Among development agencies, the Bolivian section of DED (German Development Service), who sees itself as a pioneer and leader in promoting and implementing successional agroforestry systems, identifies external mid- to long-term support as important requirement to support the entire project cycle from diffusion, generating acceptance, planning and implementation to marketing of products. In this context processing of products from agroforestry plots is given high priority to improve income generation through value adding. This corresponds to a general tendency of demand-based, not highly subsidised projects that are economically viable without continuous support from agencies. To reach this sustainability, acceptance, transport and marketing issues need to be involved.

GtZ (German Technical Cooperation), rather than classical implementation ‘on the ground’, targets decision-makers and researchers, e.g. supporting the World Agroforestry Centre – University of Hohenheim cooperation Trees in Multi-Use Landscapes in Southeast Asia (TUL-SEA), which aims at developing a decision support tool box for planning of tree-based systems. Other European development

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[30]A model on Water, Nutrient and Light Capture in Agroforestry Systems developed by the World Agroforestry Centre in Indonesia; a close cooperation between both institutions exists. Predominantly biophysical model that runs on a daily time step and plot levels, it is appropriate to simulate interactions and competition between intercropped plants.

[31]Forest, Agroforest, Low-value Landscape Or Wasteland? Developed by the World Agroforestry Centre, Indonesia. Runs on yearly time step and landscape level, focuses on decision-making in land use options.

[32]The Land Use Change Impact Assessment tool developed at University of Hohenheim simulates land use dynamics and their effects on soil fertility and water balance at daily time step on landscape level. Coupling to a socio-economic and decision-making model is being carried out.

[33] Agroforestry in Landscape Mosaics, a research project conducted by ICRAF, Yale and Georgia universities.

agencies like DFID or DANIDA also closely coordinate their efforts with the World Agroforestry Centre, while at the same time conducting own projects, often emphasizing implementation of small-holder schemes including nurseries.

10 Conclusions

Agroforestry is a set of design principles and numerous possible systems exist, which cover a wide range of diversity and complexity. Due to its adaptability agroforestry can be implemented in every ecosystem where trees can grow. Trees can improve marginal soils and preserve moisture in dry climates or under erratic rainfall. Agroforestry includes and combines with low cost and low input techniques and is apt for resource-poor farmers as it enables relative independence of external inputs. On the other hand, such systems do not exclude the application of innovative techniques. Design should combine local knowledge and state of the art science to make use of the most adapted plant species.

A main characteristic of agroforestry is its potential for diversification. This strategy allows to minimise biophysical and economic risks and to avoid labour peaks. A broad palette of products provides a balanced alimentation as well as many other goods needed in the household, which makes diversified systems suitable for subsistence farming.

Regarding commercialisation of products, diversified systems may require different marketing strategies for every product. They can certainly not compete with commercial high input monocropping systems as high yields are usually paid with high inputs and/or high risk – both are not affordable in a small farmer's reality. On the other hand, agroforestry systems, if well planned, deliver a continuous supply of different products throughout many years.

Through intensified nutrient mobilisation and cycling agroforestry systems have the potential to preserve natural resources, to protect and even to rehabilitate soils. These characteristics benefit the entire society and especially in densely populated areas upstream-downstream relationships in watersheds, mitigation of climate change or recreation value are now taken into consideration. However, payment schemes for environmental services are still underdeveloped, which hampers motivation to invest in environmentally friendly systems.

In conclusion, agroforestry systems usually do not aim at maximum short-term profit, but due to their adaptability enable an optimised and sustainable resource use. They have the potential to improve self-sufficiency and thus food security through risk minimisation and provide additional income from side products.

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12 Annex

Strategic directions elaborated during the ICRAF 25th anniversary conference (2006) include the following:

Linking tree crops with markets

In this context the development of a sustainable seed and seedling system along with a sound management of agroforestry resources is needed. Appropriate approaches should target small-scale strategies which provide regional and local benefits through participation, training and extension of farmers, combined with the access to local planting material.

In addition farmers' and enterprises' access to markets should be improved along the supply chain by developing small farmer credit schemes, improvement of post-harvest processing and the promotion of product differentiation and niche market development and on the political level by lobbying on policy improvements for forestry products.

Research, information sharing and capacity building

Optimizing the function of soils with respect to optimum AF-practices and ecosystem functions implies closing some major knowledge gaps, in particular with regard to land quality indicators, the impact of human health (e.g. HIV/AIDS) on the adoption of certain management practices, the determinants of the adaptive and adoptive advantages of technological options for sustainable soil fertility management.

To upscale and spread applicable methods, information on key issues, mechanisms and technology options must be gathered, evaluated and supplied to decision makers at various levels. Shaping an ecologically sound and economically efficient chain linking resource management, system intensification, market access and policy finally requires the cross-scale integration of stakeholders at all levels, including the empowerment and participation of farmers and particularly of vulnerable groups. Action has to be taken to ensure information sharing, the tuning of appropriate technologies with and capacity building of all these stakeholder groups.

Enhancing environmental services

Increasing farmers' resilience especially in drought-prone areas requires to promote natural biodiversity and traditional knowledge but also to increase yields through establishing good management practices and advanced local knowledge on species characteristics, cultivation methods, products and markets.

At the same time, environmental services delivered to society primarily comprise watershed management, the use and conservation of biodiversity in working landscapes, the mitigation of and adaptation to climate change.

Watershed management and pro-poor agroforestry within watersheds need to be redesigned to better involve and interlink multiple stakeholders and link upstream resources to downstream impacts. This implies improved knowledge about the relation of trees, soil and water, land-water and land-use interaction, in particular of larger land areas.

To date direct and indirect contributions of biodiversity to rural areas are largely unknown and unexplored. The same applies to trade-offs related to different landscape configurations. Action should be focusing on the promotion of policies that take account of the potential of agroforestry to biodiversity, the role of biodiversity to ecosystem structure and function at landscape level and landscape initiatives in hotspot areas that merge biodiversity and agroforestry interests.

In addition further in-depth research on the (potential) effect of agroforestry on GHG-emissions is urgently needed and should be carried out in different agro-ecological zones in order to put into perspective the role of agroforestry in mitigation and adaptation.

This implies lobbying for the implementation of policies that recognize the multifunctional character of agroforestry, including secure land tenure regulations and the establishment of mechanisms that encourage and reward sound management practices, such as PES for carbon sequestration or biodiversity conservation.