# Smallholder Agroforestry Systems as a Strategy for Carbon Storage

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## Abstract

Many smallholder agroforestry systems in Southeast Asia are species-rich and tree-rich systems that produce non-wood and wood products for both home use and market sale. Due to their high biomass, these systems may contain large carbon (C) stocks. While the agroforestry systems of individual farmers are of limited size, on a per area basis smallholder systems accumulate significant amounts of C, equaling the amount of C stored in some secondary forests over similar time periods. Their ability to simultaneously address smallholders' livelihood needs and store large amounts of C makes smallholder agroforestry systems viable project prototype under the Clean Development Mechanism (CDM) of the Kyoto Protocol, which has the dual objective of reducing greenhouse gas emissions and contributing to sustainable development. Smallholder agroforestry systems promoted through a CDM project must be economically viable independent of C payments. Although often smallholder systems are environmentally and socio-economically viable, to enhance productivity and profitability smallholder-focused CDM projects should provide farmers with technical and marketing assistance. To assure success, project sites should meet a set of preconditions, including: areas of underutilized low-biomass landuse systems that are available for rehabilitation; smallholders interested in tree farming; accessible markets for tree products; a supportive local government and sufficient infrastructure; and a transparent and equitable relationship between project partners. Questions of leakage and additionally should not be problematic and can be addressed through the project design and establishment of quantifiable and equitable baseline data. However, smallholder-focused CDM projects would have high transaction costs. The subsequent challenge is thus to develop mechanisms that reduce these costs: (a) the costs associated with information (e.g., technology, markets) more accessible to multiple clients; (b) facilitating and enforcing smallholder agreements and (c) designing feasible monitoring systems.

## Introduction

Tree-based land-use systems – natural forest, forest plantations and agroforestry systems – sequester $CO_2$ through the carbon (C) stored in their biomass. By promoting land-use systems which have higher C contents than the existing plant community net gains in C stocks (hence sequestration) can be realized. The most significant increases in C storage can be achieved by moving from lower-biomass land-use systems (e.g. grasslands, agricultural fallows and permanent shrublands) to tree-based systems. To qualify for 'certified emissions reductions' (CERs) under the Kyoto Protocol, reforestation and afforestation activities must be directly human-induced. As many efforts to achieve increased forest C storage may have negative implications for the rural

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poor, options that support human livelihoods deserve special attention. Addressing this concern, the Clean Development Mechanism (CDM) of the Kyoto Protocol will provide opportunities for investors seeking CERs to invest in developing countries for the dual mandate of reducing greenhouse gas emissions and contributing to sustainable development. Similarly, the World Bank has initiated the Community Development Carbon Fund and the BioCarbon Fund to link the enhancement of local livelihoods with C investment projects. Tree-based C sequestration projects are eligible for the CDM and the World Bank funds.

Southeast Asia provides an attractive environment for C investment. Best estimates indicate that there are 35 million hectares of *Imperata* grasslands in Southeast Asia (Garrity et al. 1997). Originally forests, these lands include pure grasslands, cyclic fallows and shrublands, and are acknowledged to be underutilized. There is clear interest, at both the governmental and smallholder farmer levels, to convert some of these *Imperata* grasslands and other degraded lands to more productive landuse, including tree-based systems (Roshetko et al. 2002; Tomich et al 1997). The establishment of agroforestry systems on underutilized sites would sequester C and could prevent further deforestation by providing on-farm sources of trees (Sanchez 1994; Schroeder 1994). Agroforestry is one means by which smallholder farmers could benefit from C investment projects (Smith and Scherr 2002; CIFOR 2000; Sampson and Scholes 2000). Smallholder agroforestry systems maintain high tree densities and may contain high C stocks. On a per area basis tree-rich smallholder systems accumulate a significant amount of C, equaling the amount of C stored in some secondary forests over similar time periods (Tomich et al 1998). Their ability to address smallholder' livelihood needs and simultaneously store large quantities of C make tree-rich smallholder agroforestry systems possible prototypes for CDM-type projects. Individual types of agroforestry systems differ greatly as do the conditions under which each type is appropriate. A set of guidelines is needed to help identify the type of agroforestry systems and conditions that are most promising for CDM-type projects. The questions we address here are: What types of agroforestry systems are appropriate for C storage? What types of enabling conditions favor smallholder benefits and project success? What type of technical assistance can enhance smallholder agroforestry systems? Additionally, we address questions of additionality, leakage, and permanence from a smallholder agroforestry systems point of reference[1].

## ■ What types of smallholder agroforestry systems are appropriate for CDM?

Agroforestry systems are land-use systems in which woody perennials (trees, shrubs, palms, bamboos) are deliberately used on the same land management unit as agricultural crops (woody or annual), animals or both, in some form of spatial arrangement or temporal sequence (Huxley and van Houten 1997). Smallholder agroforestry systems traditionally produced multiple goods mainly for home consumption, now most are at least partially market-oriented. Depending on local needs or opportunities, systems may

[1] The other externalities, such as maintenance of hydrological functions, serve another set of uses and stakeholders and as such command separate payments from corresponding beneficiaries bringing in additional returns by themselves. The interface between earnings from carbon payments and payments for other environmental services deserves another exposition in a separate paper.

focus on tree crops, agricultural crops, livestock or a combination. These various systems also differ greatly in size, species component, tree density, longevity and management intensity. Smallholder systems hold potential for C sequestration as a means of converting low-biomass landuse systems (e.g. grasslands, agricultural fallows and permanent shrublands) to tree-based C-rich systems.

Not all smallholder agroforestry systems hold the same potential. To evaluate various smallholder systems from a C sequestration perspective, we may group them into the following categories: agroforests; tree gardens; plantations; improved fallows; rows or scattered trees; livestock systems; community forests and assisted natural regeneration. Our classification of smallholder systems covers the same landuse systems appraised for CDM-type projects by Smith and Scherr (2002) and Boer and Wasrin (2002). However, the landuse categories suggested by each set of authors differ due to perspective. The key characteristics that differentiate our categories are: tree density; time averaged C stocks; and products from the system. A short description of each smallholder agroforestry system category and their characteristics are given in Table 1.

Tree density is important as it relate directly to the systems' ability to store C. Simply put more trees – denser spacing – equals higher C stored per area. However, to accurately compare C stocks of different landuse systems a scale is required that adjusts the age and rotation length to a common base. Tomich et al (1998) recommends using time-averaged C stocks for comparison between systems. The time-averaged value is half a system's C stock at its maximum age or rotation length. Agroforests, tree gardens, plantations and community forests all contain high tree density. However, those systems with longer maximum ages have higher time-averaged C stocks. It is worth noting that homegarden systems contain lower C stocks than other 60-year systems because they contain a significant numbers of low-biomass, but nonetheless economically important, species such as coconut and banana. They may also have low tree density rates than agroforest and forest systems. There is no fixed density or planting pattern for trees growing scattered on farmlands or in silvopastoral systems. Tree densities in these systems are commonly 50-400 $ha^{-1}$ (Paterson et al 1996). This is significantly less than agroforests, gardens and plantations, which commonly contain 625-850 trees $ha^{-1}$, assuming tree-spacing of 3x4 to 4x4 meters, or more. Data concerning the C stocks of scattered tree and silvopastoral systems is not readily available. However, considering that tree stocking rates are only 8-47% of other systems it can be assumed that these systems contain much low C stocks and offer a less attractive C investment option. Additionally, livestock, the main component of silvopastoral systems, are a significant contributor of methane and nitrous oxide, greenhouse gases that are accounted under IPCC guidelines (Sampson and Scholes 2000). Improved fallows/intercropping and assisted natural regeneration are transient systems commonly used to establish any tree-based landuse system. Both are appropriate methods by reach to establish a tree-based smallholder agroforestry system for C sequestration. Intercropping is particularly appropriate as the management practices undertaken to assure good agricultural crop yields – cultivation, weed control, fertilization – also enhance tree survival and growth; and the agricultural crop yields will provide the farm family with food and income.

Systems that produce a wide variety of tree products, both wood and non-wood, are preferred by smallholders as a means of securing tree products for household needs, generating income and limiting risk. The great majority of any tree-based agroforestry system's aboveground C stock is found in the wood of the trees. Most non-wood tree products – fruits, vegetables, spices, oils, resins, etc – can be harvested with negligible impact on the C stock of a system. The data in Table 1 is from systems that primarily produce non-wood products. Conversely, the harvest of wood products, particularly timber in single-objective plantations, has a direct negative impact on the systems C stock and raise concerns of 'permanence'. However, a limited amount of timber or other wood products can be harvested from a smallholder agroforestry system and still achieve appreciable C sequestration. Based on data collected in a 13-year-old homegarden systems, Roshetko et al (2002) projected time-averaged C stocks assuming current aboveground C stocks of 59.0 Mg $ha^{-1}$, a maximum system age of 60 years, 20% of the growing stock harvested for timber at year 20 (see Table 2). These projections estimated time-averaged aboveground C stocks of 118.0 and 104.4 Mg $ha^{-1}$, that are 115.8 Mg (52.9 times) and 102.2 Mg (46.5 times) greater than the time-averaged C stock of *Imperata* grasslands/agricultural fallows 2.2 Mg $ha^{-1}$ (Palm et al. 1999), which are the types of underutilized landuse systems that would be targeted for conversion to smallholder agroforestry in a CDM-type project. We feel these projections are fair estimates, as they are similar to the aboveground C stocks of 60-year-old community forests, 114-123 Mg $ha^{-1}$, assuming aboveground C is 65-70% of total C (Tomich et al. 1998). It is also likely that smallholders would employ periodic, rotational harvesting, maintaining higher C stocks than projected here. This analysis demonstrates that smallholder systems can sequestrate C while also producing timber.

Tree density and tree rotation age are not the only factors that affect an agroforestry system's C stock. The soils of agroforestry systems contain significant quantities of C also. Generally the amount of C stored in a system's soil remains steady or increases slowly with time, but decreases as a portion of the systems total C stock as the tree component grows and dominate the system. Studies in Indonesia show that the portion of C stored in 13-year-old homegardens, 30-year-old agroforests and 120-year-old natural forests were 60%, 60% and 20% respectively (Roshetko et al. 2002; Hairiah 1997; Tomich et al. 1998). Pre-existing soil C levels are an important baseline that will be measured at the beginning, and monitored throughout the duration, of any C sequestration project. Any loss in soil C will have a negative impact on the C sequestered over the life of the project. Cleaning, weeding, burning and relocation of biomass are common management practices that lead to steady loss in soil C. For example, when these practices are applied in natural forests or grasslands soil C losses of 20-50% can occur within a few years (Sampson and Scholes 2000). Such losses are not easily reversed by converting fallow lands back tree cover (Detwiler 1986). The soil C levels on such sites are expected to increase for decades or centuries (O'Connell and Sankaran 1997, in Schlamadinger and Karjalainen 2000). Appropriate management practices are required to protect against the loss soil C stocks. It is recommended that cultivation of crops be limited to the first 1-3 years when the tree-based agroforestry system is being established and that management practices control soil erosion and maintain/return biomass to the soil. Model simulations indicate that these soil management practices can maintain, and possibly increase, soil C levels, soil nutrient levels and system sustainability (Wise and Cacho 2002).

In summary, to achieve high stocks of quantifiable sequestered C, smallholders should convert low-biomass landuse systems into agroforestry systems that maintain high tree density, contain species with long maximum age, manage the system for long rotation and manage the soil to avoid a loss of baseline C. It may also be beneficial to limit the number of low-biomass species – such as coconuts and bananas. These considerations must be balanced with livelihood and market objectives of the smallholders' management plan. Carbon is a new and mysterious product for smallholder farmers, even less tangible than other environmental services – watershed protection or biodiversity conservation. Farmers must feel confident that they will benefit from their efforts. The agroforestry systems developed through a CDM-type project must be socially and economically viable independent of C payments; not intended solely to provide society with C sequestration services. The systems should be multiple species, with the mix determined by household needs and market demand. Management must be flexible to limit risk and enable farmers to adjust to changing market opportunities (Mayers and Vermeulen 2002; Tyynela et al 2002). Any income received from C payments should be treated as an additional return for the service. This approach will help protect smallholders from project or market failure. Within the domain of economically viable agroforestry systems, clear opportunity exists for smallholders to select management practices that lead to higher C stocks at the system level. C sequestration project may not make farmers rich, but they could enhance local livelihoods, assuring that smallholders benefit from C investment.

## ■ What type of technical assistance can enhance smallholder agroforestry systems?

Demise in the area or availability of local forest resources can create socioeconomic opportunities for smallholder farmers to expand tree-farming systems. This type of an agroforestation[2] process has been documented in Sri Lanka (Gunasena 1999), Bangladesh (Byron 1984), North Mindanao, the Philippines and the highlands of Kenya (Place et al. 2002). Smallholders developed these tree-farming systems to meet household needs and market demands, reduce risks, develop private tree resources, diversify income streams and make better use of their limited labor and financial capital. Scherr (1999; 1995) identified the following conditions that favor the development of successful smallholder agroforestry systems in Central America, the Caribbean and Kenya: accessible markets, available planting material of species that are appropriate for the site and agroforestry system, and experience with tree planting and management. To assure success, a smallholder agroforestry CDM-type project should provide technical support that facilitates the development of similar supportive conditions.

An interest in and willingness to establish tree farming, does not always translate directly to technical capacity and success. Although smallholder agroforestry systems have developed in many areas, there are a greater number of areas where such systems have

[2] Agroforestation refers to the establishment of smallholder agroforestry systems, and implies land rehabilitation through the establishment of a tree-based system and intensification of land management.

not yet developed. There are number of reasons that might stifle the development of smallholder agroforestry. In many areas smallholder farmers have little experience with intensive tree planting; and little access to technical information and germplasm (seed or seedlings). Potter and Lee (1998) found that the ability of smallholders to plant trees or expand traditional tree-based systems is limited by resource scarcity, absence of technical capacity and experience, as well as market and policy disincentives. In Lampung, Indonesia a team of socioeconomic, forestry, horticulture and livestock specialists determined that smallholder agroforestry systems and the productivity of those systems are limited by a lack of technical information, resources and consultation (Ginitings et al. 1996). Across Southeast Asia, smallholders' tree planting activities are often restricted by limited access to quality planting material, poor nursery skills (Gunasena and Roshetko 2000; Harwood et al 1999) and a dearth of appropriate technical information (Gunasena and Roshetko 2000; Daniel et al 1999).

Experience indicates that conditions that support the development of smallholder agroforestry systems can be created by focusing on four key issues – quality germplasm of appropriate species; tree propagation and nursery skills; agroforestry system productivity; and product marketing.

**Quality germplasm** is an important innovation and intervention, particularly for smallholders farming marginal lands, who have low capacity to absorb high risk and few resource options (Simons et al. 1994; Cromwell et al. 1993). A model of general tree germplasm pathways indicates that quality seed is most often controlled by the formal seed sector (research organizations, government agencies, and forest industry) to which smallholders have little access (Harwood et al. 1999). Efforts must be made to link smallholders with these sources of quality germplasm and expand smallholder access to a wider range of species that are suitable to the biophysical and socioeconomic conditions they confront. These efforts should include the development of farmer trials designed collaboratively by project staff and farmers to i) demonstrate the advantages of good quality germplasm and new species; ii) inspire local innovation; and iii) serve as a future source of quality on-farm seed production (Roshetko 2002).

Experience indicates that **seed collection/management and tree nursery management training** are a proven mechanism to building local technical capacity, leadership and planning skills, confidence and independence. Potential developments from these capacity building activities include the evolution of commercial tree nurseries and even local-based tree seed companies that collect and sell tree seed (Tolentino et al. 2001; Koffa and Garrity 2001).

The **productivity of most smallholder agroforestry systems** can be improved by addressing the priority issues resulting from a participatory problem identification process. Key issues are likely to include: species selection / site matching; tree farming systems that match farmers' land, labor and socioeconomic limitations – to include annual crops, tree crops, intercropping and understory cropping options; pest and disease management; and soil management. Likewise, the productivity of many smallholder agroforestry systems can be improved by enhancing farmer's **market linkages and knowledge**.

Smallholders generally have weak **linkages with markets** and poor access to market information (Hammett 1994; Arocena-Fransico et al. 1999). Predo (2002) found that tree farming was more profitable than annual crop production, but uncertain marketing conditions deterred tree planting. The existence of accessible markets for tree products is also a vital feature of the project site (Landell-Mills 2002; Sherr 1999 and 1995). Otherwise, the development of economically viable systems is doubtful. Initial efforts should focus on: quantifying current and future demand for agroforestry products in local, national and regional markets; and identify the market channels, both official and unofficial, that are accessible to smallholder farmers as well as the problems faced by producers (smallholders) and traders that hamper the utilization of these channels. Once these basic conditions are known, it should be possible to work on enhancing product quality to meet market specifications and expand smallholders' role to include some post-harvest activities (sorting, grading and semi-processing).

### ■ What types of enabling conditions favor smallholder benefits and project success?

Efforts to achieve increased C storage in landuse systems will not automatically lead to positive impacts on local livelihoods. Many such efforts could have negative implications for rural residents, particularly the poor, by restricting access to land or binding communities to long-term landuse management practices that do not meet their socioeconomic needs. Without inducing a flow of additional benefits to local residents, a CDM-type carbon project cannot achieve its objectives, as the community will not accept restrictions on their current landuse options for a nebulous social goal accrued to an outside investor. It is thus important to identify the enabling conditions that favor a flow of project-induced benefit to local residents and community satisfaction thereby promoting project success. To date there is limited experience with C sequestration projects that seek to enhance local livelihoods. However, sufficient similarities exist between the goals of CDM-type projects and those of timber out-grower schemes, tree-based development projects, and other environmental service projects that valuable lessons learned can be drawn from these latter activities. Much of this section derives lessons learned from these natural resource-based activities. We discuss four categories of enabling conditions that would enhance smallholder livelihood and welfare through a CDM project: integrated planning and project design; establishing clear, stable and enforceable rules of access to land and trees; managing high transaction costs; and ensuring dynamic flexibility for co-generating other environmental services.

**Integrated planning and project design.** Smallholders invest in trees is one component of their overall landuse systems, which is integrated closely with off-farm activities that generate income and livelihood. Indeed, the following factors are found to be positively correlated with successful smallholder tree planting activities – adequate food security; off-farm employment; sufficient household labor; higher education levels; access to land that is not needed for food crop production, and lower risks (Tyynela et al. 2002; Yuliyanti and Roshetko 2002; Predo 2002). Since smallholders are not likely to be solely interested in carbon storage a CDM-type project should integrate its activities into the household's and community's broader development plans (Tyynela et al. 2002; Desmond and Race 2002; Bass et al 2000), particularly agriculture productivity or other issues directly related to agroforestry such as maintaining environmental services. Efforts should be made to identify the community's development priorities, even when such priorities do not formally exist. While a CDM- type project might not be able to directly address problems of infrastructure, health care or education, it should be aware of these issues and when possible provide support or alter activities so as not to impede progress. The project should also help to form or strengthen community institutions and build their capacity in relation to: agroforestry; negotiations; planning and leadership; and possibly in the concepts of carbon sequestration, monitoring and transactions (CIFOR 2000; Tipper 2002). In the long-term, this type of community-level capacity building may be the most significant contribution to the development of a low-cost, successful smallholder agroforestation process that supports local livelihoods and reduces greenhouse gas emissions through C sequestration.

**Establishing clear, stable and enforceable rules of access to land and trees.** Clear land tenure and tree use rights are imperative for the successful implementation of any tree planting activities or C sequestration project (Tomich et al. 2002; Sherr 1995 and 1999; Desmond and Race 2000; Predo 2002). Without guaranteed rights to utilize the trees, smallholders are not likely to plant nor tend trees. Delineating and defining land and tree access rights, whether individual or commonly held, must be a high priority for the site selection phase of a C sequestration project (Bass et al. 2000). Securing tenure rights can be one reward resulting from the project, however it should not be the only 'carrot' to get people to plant trees. Tenure rights must be part of a wider negotiation process that addresses the communities' broader development needs. Such a negotiation process should be a fundamental part of the project design, as discussed below.

**Managing high transactions costs.** A successful CDM-type project will require close collaboration between four types of partners - project staff, governments (both local and national), community of smallholder farmers, and independent local institutions; each partner having a specific role. In brief, the project staff may be responsible for project implementation and coordination while the government formulates a supportive regulatory and institutional environment. Both groups should specifically identify and rectify policy disincentives that discourage tree farming (e.g. issues regarding land tenure, tree harvesting rights, marketing rights and taxation of tree products). Smallholders are responsible for establishing and managing agroforestry systems that sequester and store verifiable quantities of C – and meet their livelihood needs. One non-partisan institution, locally active and credible, may serve as an independent party to resolve conflicts among the partners (CIFOR 2000; Mayers and Vermeulen 2002; Tyynela et al 2002) while another would verify and monitor carbon sequestration. All parties should be treated as equals and actively participate in the project design. The objectives and activities of the project, as well as the responsibilities and benefits of each party should be determined through negotiation - not unilaterally set by the project (Tyynela et al 2002; Mayers and Vermeulen 2002; Desmond and Race2000). This negotiation process must be participatory, transparent and agreeable to all partners.

Specifically, farmers must understand the services they are providing and agree with the benefits they are to receive. Channels of communication must always be open. The terms of engagement should be equitable, realistic and formalized in a legal contract. It is likely that there will be misunderstandings and conflicts. Thus, the contract should be flexible and renegotiable (CIFOR 2000, Tyynela et al. 2002; Desmond and Race 2002; Fikar 2002).

With these requirements and the likely engagement of a large number of smallholder tree farmers, the single largest hindrance to the development of smallholder systems as a CDM project type is high **transaction costs** that include: (a) the costs associated with making information (e.g., on technology, markets and market players) more accessible to multiple clients; (b) facilitating and enforcing smallholder agreements and (c) designing feasible monitoring systems. While these (high) costs are justifiable under the CDM as the extra costs required to achieve more equity and welfare, they are not likely to be underwritten by C investors who are more interested to secure C credits and who have other alternatives investment opportunities (e.g., large tree plantations). Thus, in order to attract investors to smallholder-oriented projects, co-funding mechanism are needed such as multilateral funding structures with specialized institutions who would guarantee investors a specified amount of carbon credits from higher cost smallholder-oriented project that included significant social benefits (CIFOR 2001). Similarly, the transactions costs, including costs for intermediate services – such as project development, marketing, contract negotiations – could be provided by a specialized institution (CIFOR 2000). It has also been suggested to combine smallholder-oriented projects with other development or research activities as a means of expanding the required funding base. These mechanisms are promising, however, to date there has been little experience with regarding the implementation and operational costs of smallholder-oriented C projects (Tomich et al. 2002). The subsequent challenge is to gain experience in the operation of smallholder-oriented projects and develop mechanisms that reduce these costs.

■ **Ensuring dynamic flexibility for co-generating other environmental services.**

Restrictions on the management of trees to ensure permanence in storing carbon imply that a forest-like ecosystem is established. Various smallholder agroforestry systems are likely to generate joint products and services, such as biodiversity conservation and watershed protection. These join products/services generate benefits to different sectors of society, and as such, are likely to warrant payments to reduce scarcity and ensure sustainability. Markets for these environmental services are in different stages of development and also need to be enhanced to assure that they benefit smallholders. In fact the development of pro-poor payments for landscape amenities (e.g. eco-tourism) and watershed services also requires the same enabling conditions that were discussed for carbon markets above. Hence, the design of CDM projects, tree product marketing, tenure arrangements and institutions for underwriting transactions costs need to be flexible to allow for the multiple products and services likely to be generated by the same tree-based systems.

## Additionality, Baselines, Leakage and other factors

There are a number of other important factors that must be satisfied if smallholder agroforestry systems are to be a viable CDM-type project type. Chief among these are the criteria of 'additionality', 'baselines' and 'leakage'. **Additionality** requires that C stocks accrued to a C sequestration project are 'additional' to those that would occur without the project. This is not a straightforward situation. Tomich et al. (2002; 1998) report that smallholder do spontaneously convert low-biomass ecosystems to productive and profitable agroforestry forestry. Since agroforestation of these low-biomass lands occurs without outside intervention, it might be argued that smallholder agroforestry systems are a recognized 'business as usual' practice that should be exclude from CDM-type projects. This would be inaccurate. The biophysical and, more importantly, the socioeconomic conditions of degraded sites are not homogeneous. There are 35 million hectares of under-productive *Imperata* grasslands across Southeast Asia that are not being rehabilitated (Garrity et al. 1997; Tomich et al 1997). A minimum threshold of enabling conditions that make successful smallholder agroforestation possible, do not exist in these areas. Certainly a project that facilitated the development of conducive enabling conditions for smallholder agroforestation should qualify for C credits. It might also be argued that left alone low-biomass ecosystems would become secondary forests through the process of natural regeneration. This is likewise inaccurate, as many of these sites are prone to cyclical fires, which eliminates natural regeneration (Friday et al. 1999; Wibowo et al 1997). Experience in Indonesia and the Philippines (Friday et al. 1999) and India (Poffenberger 2002; Saxena 1997) demonstrate that specific action by individuals or groups is a more successful strategy for rehabilitation (afforest/reforest) of these sites then reliance on natural regeneration. To make such action possible the enabling conditions mentioned above are required.

Quantifying the amount of 'additional' carbon sequestered by project activities will rely upon the establishment of a reliable and cost-effective **baseline data**, that consider pre-project scenarios, with project scenarios and without project scenarios. Currently there are no standard methods for the development of baseline data. To date most C sequestration and averted deforestation projects have used project-specific methods that yield accurate data for local (project) conditions (Watson et al 2000; Ellis 1999). The disadvantages with this approach is that i) project managers may choose methods that maximize C credits (Watson et al 2000); and ii) comparison between projects may not be easy. Thus, there remains a need to develop a set of standard methods that flexible enough to address various project conditions, but consistent enough to yield reliable and comparable baseline data. Another problem with developing baseline data for a smallholder project is the difficulty of dealing with a plethora of landowners, their objectives, landuse systems and other factors (Roshetko et al 2002).

**Leakage** is the loss of C, primarily as woody biomass, in non-project areas due to changes in landuse practices resulting from activities within the project area. The threat of significant leakage from project that convert low-biomass ecosystem to smallholder agroforestry systems is low to non-existent. For example the conversion of *Imperata* grasslands is not likely to greatly alter local land-use practices that would result in the loss of C elsewhere, particularly when abundant *Imperata* lands remain (Roshetko et al

2002). A loss of crop productivity is not anticipated, as the degraded lands in question, while possibly biophysically suitable, are not currently utilized for crop production. Thus agroforestation of these lands will not result in deforestation elsewhere to replace a loss of agricultural land. In fact, agroforestation of low-biomass ecosystems may provide 'negative leakage' by preventing deforestation or forest degradation through the establishment of on-farm sources of trees (Smith and Scherr 2002, Sanchez 1994; Schroeder 1994). The opportunity costs of converting low-biomass lands is low as no competing landuse systems have developed in many areas were degraded lands are common. Besides leakage there are other potential negative impacts that should be addressed. Access to products from low-biomass lands would be obstructed by the development of smallholder agroforestry systems. The burden of this landuse change would fall more heavily on disadvantage community members who would have collected fuelwood, fodder or other the products from degraded lands. From the perspective of joint forest management in India, Saxena (1997) suggests that such negative impacts can be managed by developing alternate tree and grass resources specifically for the disadvantaged. Such an approach could easily be integrated into a smallholder agroforestation project at the level of either communal or individual plots. It is possible negative market impacts could result if a large number of smallholders began to produce a single or few commodities in large quantities without sufficient market information. This situation can be avoided by developing smallholder agroforestry system that produce multiple products for both home and sale; and implementing market studies to identify accessible markets for key products and project future demand and prices.

**Permanence** concerns the longevity and stability of a carbon stock. The carbon stocks in any landuse system, although theoretically permanent, are potentially reversible through human activities and environmental change, including climate change (Watson et al. 2000). It is this inherent risk that makes LULUCF activities less attractive than emission avoidance or reduction activities in the energy sector. With regards to C permanence there are perceived advantages and disadvantages to carbon projects that have a conservation-, industrial forestry-, and smallholder-focus. Conservation type projects are said to represent permanent C storage systems because they are protected through legal, political or social action. However, averted deforestation is not yet an eligible CDM project type and the amount of additional C that can be sequestered by a mature forest is much less than a newly planted 'tree-based system' (Watson et al. 2000). Conservation projects must also meet the criteria of 'additionality' and 'leakage'. Industrial timber and pulp plantations may represent a viable project type because they are managed by a single entity on a fixed long-term basis and rotational harvesting can be employed to maintain high C levels. During the terms of a stipulated period the C stocks in industrial forestry lands are reliably permanent. However, industrial forestry projects are criticized because they represent 'business as usual' practices reorganized to benefit from carbon payments (Noble et al. 2000). Additionally, both conservation and industrial forestry projects provide limited direct advantages to smallholders, but restrict access to land that smallholders may have previously used. This makes their contribution to local livelihoods and thus sustainable development questionable. Smallholder-oriented projects can be regarded as risky because they involved numerous farmers with various and flexible land management systems (Smith and Scherr 2002; Bass et al. 2000), thus the carbon stocks in these systems might be considered unstable and unpredictable. However, the development of tree-rich, diversified, economically viable smallholder systems provides direct livelihood benefits to the farmers – a priority for CDM-type projects. Additionally, smallholders' flexible land management practices are a strength that allow farmers to adapt their agroforestry systems to fluctuating markets or other socioeconomic conditions. Tree cover might fluctuate at the farm level, but at the community – project – level tree cover would continue to expand under the supportive influence of the enabling conditions discussed above. These newly established tree-based systems would continue to sequester C for 20 to 50 years (Watson et al 2000), significantly increasing the local C budget of the formerly low-biomass landuse systems. We suggest that smallholder systems not only provide more benefits for smallholders, but when combined with secure land tenure, supportive governments, technical and marketing support, and other enabling conditions, also reduce risks for both smallholders and the C investors.

## ■ Conclusion

Smallholder agroforestry systems are a viable strategy for C sequestration. However, not all smallholder systems hold the same potential for high C sequestration. To achieve high C stocks, smallholders should convert low-biomass landuse systems into agroforestry systems that maintain high tree density, contain species with long maximum ages, manage the systems for long rotation and manage soil to avoid a loss of baseline C. The systems are likely to include multiple species and species types (timber, fruit, vegetable, species, etc) with the species mix being determined by livelihood needs and market opportunities. These systems must be economically viable independent of C payments. Any income received from C payments should be treated as an additional return for the service. Because smallholders often have limited linkages outside their communities, the economic and C sequestration potential of their systems can benefit from technical and marketing assistance. However, many efforts to achieve increased landuse based C storage could have negative implications on local livelihoods by restricting access to land, land management options or product use. To avoid such problems the following conditions should exist at any CDM-type C sequestration project site. Land and tree tenure rights should be recognized or available to local residents. Farmers should be interested in developing tree-based agroforestry systems. They should have food security and sufficient access to labor and technical inputs (germplasm, information, expert consultation, training) to establish and manage viable agroforestry systems. A successful CDM-type project should be designed and implemented in close collaboration between project staff, governments, smallholder farmers and independent local institutes. The objectives and activities, as well as the responsibilities and benefits for each partner should be determined through negotiation, not set unilaterally. The negotiation process must be participatory, transparent and agreeable to all parties. Terms of the project should be formalized by a contract, with should be flexible to address potential conflicts. The project should not stand separate from other local activities, but rather be integrated into the community's broader development plans. Concerns over the permanence of the C stocks in smallholder agroforestry systems are not different from those of other fix-rotation landuse systems. The single greatest hindrance to developing smallholder agroforestry systems as a CDM project type is the high transaction costs related to working with large number of smallholder farmers. The subsequent challenge is to develop mechanisms to reduce these costs through multilateral assistance, funds from private trusts and governments. C sequestration projects may not make farmers rich, but if properly implemented in a participatory manner, they could enhance local livelihoods, assuring that smallholders do benefit from C investment.

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Table 1. Categories and description of smallholder agroforestry systems and their characteristics from a C storage and CDM prototype perspective.

| Smallholder Agroforestry System | Tree Density | Time averaged C stock Mg ha$^{-1}$ | Products | Comments |
|---|---|---|---|---|
| **Agroforests –** multistory combinations of various tree crops, often with a predominance of a few species of high economic value, in an extensive system resembling a forest. | High tree density. | 175 (60 yrs) | Multiple products for household use and market sale. | Privately owned or communal land rights. Commonly 1-10 ha. Communal areas maybe up to100 ha. May have developed from natural forests. Provides watershed and biodiversity environmental services. |
| **Tree Gardens –** multistory combinations of various tree and annual crops, including homegardens (HGS) and forest gardens. | High tree density. | Forest 175 (60 yrs)<br>HGS1 140 (60yrs)<br>HGS2 120 (60yrs)<br>Rubber 100 (30yrs)<br>Coffee 80 (25yrs) | Multiple products for household use and market sale. | Usually privately owned, 0.25-5 ha, maybe as small as 0.10 ha. Communal gardens may be up to 100 ha. Provides watershed and agro-biodiversity environmental services. HGS2 includes timber production on a 20-year rotation. |
| **Plantations –** of timber, fruit or other commodity (coffee, rubber, etc) containing one or few species. | High tree density. | Timber 150 (40yrs)<br>Rubber 95 (25yrs)<br>Oil Palm 90 (20yrs)<br>Coffee 50 (25yrs) | A few products primarily for market sale. | Privately owned, 0.25-5 ha. Possibly provides watershed environmental services. These systems are vulnerable to market fluctuations and contain very low biodiversity levels. |
| **Scattered Trees on Farmlands –** on farms, including border plantings, contour plantings, windbreaks, and irregularly spaced trees. | Low to medium tree density. | Unknown (Low) | Varies. Possibly multiple products for household use and market sale. | Privately owned, 0.25-5 ha. |
| **Livestock (Silvopastoral) Systems -** combining trees at irregular or uniform spacing with livestock production, including hedgerows of fodder trees used for intensive feed production. | Low to medium tree density. | Unknown (Low) | Livestock products for home use and market sale | Privately owned or communal land rights. Commonly 0.5-5 ha. Communal areas maybe up to 100 ha. |
| **Community Forest Land / Forest Preserves –** areas of natural or | High tree density. | 175 (60yrs) | Low-intensity extraction of Non- | Communal land rights, 10-1000s ha. There maybe individual rights for sub-units of 0.5- |

| | | | | |
|---|---|---|---|---|
| **Preserves –** areas of natural or secondary forests managed by communities for environmental goals (biodiversity or soil/water conservation). | | | wood products | 5 ha. Provides watershed and biodiversity environmental services. |
| **Improved Fallows / Intercropping –** combining annual crops with trees, including taungya or alleycropping systems. Often, a method used to establish a tree dominant system. | Low tree density during the development stage. | Low | Annual crops for household use during the development stage | Methods used to establish tree-based landuse systems on either private or communal lands. |
| **Assisted Natural Regeneration –** stimulating the growth of natural seedlings and saplings, may include some planting. Often, a method used to establish a tree dominant system. | Depends on site and stage of development. | Low | Low productivity during the development stage | Methods used to establish tree-based landuse systems on either private or communal lands. |

Note: Some systems definitions adapted from Friday, Drilling and Garrity (1999) and Nair, PKR. (1993).
Time averaged C stocks adapted from Tomich et al (1998), Roshetko et al (2002), and van Noordwijk et al 2002.
Information in the table is indicative, not definitive, and intended for comparison between systems.

Table 2. Project of time-averaged aboveground C stocks for homegarden systems, assuming current aboveground C stocks of 59 Mg $ha^{-1}$, 60 year rotation age, and a timber harvest in year 20 (adapted from Roshetko et al. 2002).

| **Species component** | **% of homegarden** | **Current aboveground C stock (Mg $ha^{-1}$)** | **Maximum / current age (years)** | **Maximum aboveground C stock (Mg $ha^{-1}$)** | **Time-averaged aboveground C stock (Mg $ha^{-1}$)** |
|---|---|---|---|---|---|
| Example 1 | | | | | |
| **Non-timber species –** long max. age | 60 | 35.4 | 60 / 13 | 163.4 | 81.7 |
| **Non-timber species** – short max. age | 20 | 11.8 | 30 / 13 | 27.2 | 13.6 |
| **Timber species** | 20 | 11.8 | 20 / 13 | 18.2 | 9.1 |
| Total | 100 | 59.0 | | 208.8 | 104.4 |
| | | | | | |
| Example 1 | | | | | |
| **Non-timber species –** long max. age | 80 | 47.2 | 60 / 13 | 217.9 | 108.9 |
| **Timber species** | 20 | 11.8 | 20 / 13 | 18.2 | 9.1 |
| Total | 100 | 59.0 | | 236.1 | 118.0 |