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SMALLHOLDER AGROFORESTRY SYSTEMS FOR CARBON STORAGE

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Abstract. Most smallholder agroforestry systems in Southeast Asia are tree- and species-rich systems producing non-wood and wood products for both home use and market sale. Due to their high biomass, these systems contain large carbon (C) stocks. While the 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 of similar age. Their ability to simultaneously address smallholders' livelihood needs and store large amounts of C makes smallholder systems viable project types under the Clean Development Mechanism (CDM) of the Kyoto Protocol, with its dual objective of emissions reduction and sustainable development. Smallholder systems have not developed in areas where enabling conditions do not exist. A CDM project that facilitates a minimum threshold of enabling conditions that make smallholder agroforestation possible should qualify for C credits. To secure smallholder confidence, the agroforestry systems promoted through a CDM project must be socially and economically viable independent of C payments. To assure system productivity and profitability, projects should provide farmers with technical and marketing assistance. Additionally, project sites should meet the following preconditions: areas of underutilized low-biomass landuse systems available for rehabilitation; smallholders interested in tree farming; accessible markets for tree products; supportive local governments; sufficient infrastructure; and transparent and equitable relationships between project partners. Questions of leakage and additionality should not be problematic and can be addressed through the project design, establishment of quantifiable baseline data and facilitating enabling conditions. However, smallholder-focused CDM projects would have high transaction costs. The subsequent challenge is thus to develop mechanisms that reduce the costs of: (a) making information (e.g., technology, markets) more accessible to multiple clients; (b) facilitating and enforcing smallholder agreements and (c) designing feasible monitoring systems.

Keywords: enabling conditions, local livelihoods, smallholder agroforestry, agroforestation, smallholder CDM projects, AR CDM, LULUCF, CERs, C stocks, transaction costs

1. Introduction

The IPCC Third Assessment Report (TAR) concludes that there is strong evidence that human activities have affected the world's climate (IPCC 2001). The rise in global temperatures has been attributed to emission of greenhouse gasses (GHG), notably CO_2.

Tropical forests have the largest potential to mitigate climate change amongst the world's forests through conservation of existing carbon pools (e.g. reduced impact logging), expansion of carbon sinks (e.g. reforestation, agroforestry), and substitution of wood products for fossil fuels (Brown et al. 1996, 2000). In tropical Asia, it is estimated that forestation, agroforestry, regeneration and avoided deforestation activities have the potential to sequester 7.50, 2.03, 3.8–7.7, and 3.3–5.8 Pg C respectively between 1995–2050 (Brown et al. 1996).

In 1997, during the Third Conference of Parties (COP-3) of the UNFCCC, the Kyoto Protocol was drafted which is the first international agreement that places legally binding limits on GHG emissions from developed countries (UNFCCC 1997). The Protocol, which entered into effect in February 2005, also provides for flexible mechanisms to meet carbon reduction obligations. The most relevant to developing countries is the Clean Development Mechanism (CDM) found in Article 12. Essentially, the CDM allows Annex 1 (developed) countries to meet their carbon reduction quota via activities in developing countries. During the COP-6 in 2000, parties to the convention approved the inclusion of 'sinks' (land use, landuse change, and forestry or LULUCF) projects for the first commitment period but limited to reforestation and afforestation only. The rules and modalities for LULUCF projects were finalized in 2003 during COP-9 (UNFCCC 2003a, Decision 19/CP9). Carbon credits obtained through the CDM are call certified emission reductions (CERs).

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 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 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.

Globally, the greatest potential area for expanding agroforestry practices and other forms of land-use intensification is in areas considered 'degraded' at the margins of the humid tropics, such as many secondary forest fallows, *Imperata* grasslands, and degraded pastures (Sampson and Scholes 2000). It is estimated that a total of 10.5×10^6 ha can be put into agroforestry yearly with enabling government policies such as those described by Fay et al. (1998) and Tomich et al. (1998).

A recent World Bank-commissioned study (Haites 2004) estimates that the market potential of the CDM in 2010 will be a demand for CERs of 250 Mt CO_2 equivalent (e) (varying from 50 to 500 Mt CO_2e) at an average price of US$11/t$CO_2$e. This potential is based on the assumptions of continued preference for CERs and *emission reduction units* by buyers, a sustained flow of new CDM projects, and a realization of a substantial share of the potential emission reductions in Asia. Jotzo and Michelova (2001) estimate that CDM activities could potentially supply up to 32% of the Kyoto Protocol commitments of Annex 1 countries. This could translate to US$300 million in revenues from forestry projects for the sale of 67 Mt CO_2 of CERs during the first commitment period. China and Indonesia are expected to procure most of these projects, 37% and 25% respectively (Trexler and Haugen 1995, cited in Jotzo and Michelova 2001). Trends are encouraging. To date, over US$1 billion has been invested in C credits, with the lead investors being the World Bank (US$450 million), the Netherlands (US$250 million), Spain (US$170 million) and Japan (US$140 million) (Cosbey et al. 2005).

Economic and financial analyses of agroforestry systems with potential for CDM in Indonesia are encouraging (Ginoga et al. 2004, 2005). For example, in *Gliricidia* sepium tree farms, C payments encouraged landholders to adopt less intensive practices since net revenues were higher (Wise and Cacho 2005). In the Philippines, C sequestration through *Paraserianthes falcataria*-based agroforestry systems was found to be less costly than pure tree-based systems suggesting that agroforestry systems are the more attractive option (Shively et al. 2004).

Southeast Asia contains vast areas of degraded and underutilized lands that could be used for C investment. Best estimates indicate that there are 35×10^6 ha 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 (CIFOR 2000; Sampson and Scholes 2000; Smith and Scherr 2002). 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, provide tree/forest products needed by society 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]

2. What Types of Smallholder Agroforestry Systems are Appropriate for CDM?

For the first commitment period (2008–2012), only reforestation and afforestation activities are qualified under the CDM. These are officially defined by the UNFCCC as follows (Decision 11/CP7 2001):

> "'Afforestation' is the direct human-induced conversion of land that has not been forested for a period of at least 50 years to forested land through planting, seeding and/or the human-induced promotion of natural seed sources;"

> "'Reforestation' is the direct human-induced conversion of non-forested land to forested land through planting, seeding and/or the human-induced promotion of natural seed sources, on land that was forested but that has been converted to non-forested land. For the first commitment period, reforestation activities will be limited to reforestation occurring on those lands that did not contain forest on 31 December 1989."

It should be noted that how a country defines a forest is very important in determining which activities qualify. Under the CDM,

> "a 'Forest' is a minimum area of land of 0.05–1.0 ha with tree crown cover (or equivalent stocking level) of more than 10–30% with trees with the potential to reach a minimum height of 2–5 m at maturity *in situ*. A forest may consist either of closed forest formations where trees of various storeys and undergrowth cover a high proportion of the ground or open forest. Young natural stands and all plantations which have yet to reach a crown density of 10–30% or tree height of 2–5 m are included under forest, as are areas normally forming part of the forest area which are temporarily unstocked as a result of human intervention such as harvesting or natural causes, but which are expected to revert to forest".

Depending on how a party chooses its definition, certain types of agroforestry systems may or may not be eligible for CDM. For example, Indonesia defines forests as *a minimum area of 0.25 hectare with crown cover of more than 30% and species with the potential to reach heights of* 5 m *or more* (MOF 2004). Based on this definition, agroforestry systems with crown cover greater then 30% would not be eligible for 'reforestation and afforestation', but coffee or tea systems would be as coffee trees and tea plants are both shorter them 5 meters and crown cover by associate tree species in these systems is minimum (Winrock-LMGC 2005).

Agroforestry is a 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 2004). Agroforestry systems maybe defined as 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). The period of tree cover may vary from a few to many years, as the period becomes longer the agroforestry system may resemble a forest. Smallholder agroforestry systems refer to small landholdings or parcels managed by individuals or groups of farmers. Traditionally producing multiple goods primarily for home consumption, now most smallholder agroforestry systems are at least partially market-oriented. Depending on local needs or opportunities, systems may 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 agroforestry holds 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 MOE (2003). However, the landuse categories suggested by each set of authors differ due to perspective. The key characteristics that differentiate our categories are: tree density, C stocks, and products from the system. A short description of each smallholder agroforestry system category and their characteristics are given in Table I.

Tree density is important as it relates directly to the systems' ability to store C. Simply put more trees – denser spacing – equals higher C stored per area. Those systems with longer maximum ages have higher potential C stocks. It is worth noting that homegarden systems contain lower C stocks than other 60-year systems because they contain a significant number of low-biomass, but nonetheless economically important, species such as coconut and banana. They may also have lower 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

TABLE I

Categories and description of smallholder agroforestry systems and their characteristics from a C storage and CDM prototype perspective[a]

Smallholder agroforestry system	Tree density	C stock Mg ha^{-1} (Maximum age of system)	Products	Comments
Agroforests – multistorey 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.	350 (+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 in a system that is obviously planted and managed. Includes homegardens (HGS) and forest gardens.	High tree density.	Forest 350 (+60 yrs); HGS1 280 (+60 yrs); HGS2 240 (+60 yrs); Rubber 200 (+30 yrs); Coffee 160 (+25 yrs)	Multiple products for household use and market sale.	Usually privately owned, 0.25–5 ha, could be larger or 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 300 (+40yrs); Rubber 190 (+25 yrs); Oil Palm 180 (+20 yrs); Coffee 100 (+25 yrs)	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.

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TABLE I
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Smallholder agroforestry system	Tree density	C stock Mg ha^{-1} (Maximum age of system)	Products	Comments
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 same as 1 and 2 above? – areas of natural or secondary forests managed by communities for environmental goals (biodiversity or soil/water conservation).	High tree density.	350 (+60 yrs)	Low-intensity extraction of Non-wood products	Communal land rights, 10–1000s ha. There maybe individual rights for sub-units of 0.5–5 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.

[a]Some systems definitions adapted from Friday, Drilling and Garrity (1999) and Nair, PKR. (1993). 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.

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 3×4 to 4×4 m, or more. Data concerning the C stocks of scattered tree and silvopastoral systems is not readily available. However, with tree stocking rates only 8–47% of other systems it can be assumed that these systems contain much low C stocks. 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). Considering these points we generalize that in most cases scattered tree and silvopastoral systems offer a less attractive C investment option compared to systems with high tree densities. Improved fallows/intercropping and assisted natural regeneration are transient systems commonly used to establish any tree-based landuse system. Both are appropriate methods by which to establish a tree-based smallholder agroforestry system for C sequestration. Intercropping is particularly attractive 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 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 I are from systems that primarily produce non-wood products. Conversely, the harvest of wood products, particularly timber in single-objective plantations, has a negative impact on the system's C stock and raises 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 homegarden systems with high tree density, Roshetko et al. (2002) projected C stocks assuming current (age 13 years) aboveground C stocks of 59.0 mg ha^{-1}, with a maximum system age of 60 years, and 20% or 40% of the growing stock harvested for timber at year 20 (see Table II). These projections estimated aboveground C stocks of 236.1 and 199.7 Mg ha^{-1}, that are 231.6 Mg (52.6 times) and 195.3 Mg (44.4 times) greater than the C stock of nearby *Imperata* grasslands/agricultural fallows (4.4 Mg ha^{-1}) (Palm et al. 1999), which are the 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, 228–246 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.

TABLE II

Projection of aboveground C stocks for homegarden systems, assuming current (age 13 years) aboveground C stocks of 59 Mg ha^{-1}, with 60 year maximum age, and a timber harvest in year 20 Adapted from Roshetko et al. (2002)

Species component	Species % of homegarden	Current aboveground C stock (Mg ha^{-1})	Maximum/ current age (years)	Maximum aboveground C (Mg ha^{-1}) at 60 yrs
Example 1				
Non-timber species – Maximum age of 60 years	60	35.4	60/13	163.4
Timber species – Rotation age of 20 years	40	23.6	20/13	36.3
Total	100	59.0		199.7
Example 2				
Non-timber species – Maximum age of 60 years	80	47.2	60/13	217.9
Timber species – Rotation age of 20 years	20	11.8	20/13	18.2
Total	100	59.0		236.1

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, increasing slowly with time. As a portion of the system's total C stock, soil C decreases with time 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 (Hairiah 1997; Tomich et al. 1998; Roshetko et al. 2002). 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 when practiced to excess. 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 with 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. Otherwise the CDM-type project would run the risk of becoming another top-down tree-planting project that failed by ignoring priorities and objectives of local communities (Carandang and Lasco 1998; Carandang and Cardenas 1991). Agroforestry systems that provide tangible socioeconomic benefits are less likely to be converted to other landuse system. In most cases, 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). It is recommended that farmers receive a carbon payment for tree cultivation to promote transparency and farmers' understanding of the services their agroforestry system provide. However, 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 projects may not make farmers rich, but they could enhance local livelihoods, assuring that smallholders benefit from C investment. Under conditions of strong and steady market demand smallholder polyculture or monoculture might be justified as segregated landuse sub-systems in a larger landscape mosaic. Questions of economic risk and vulnerability need to be clearly evaluated before smallholders opt for these systems.

3. What Type of Technical Assistance Can Enhance Smallholder Agroforestry Systems?

A decline in the area of local forests, or access to those 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 (1995, 1999) 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 not yet developed. There are number of factors 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 (Gintings et al. 1996). Across Southeast Asia, smallholders' tree planting activities are often restricted by limited access to quality planting material, poor nursery skills and a dearth of appropriate technical information (Daniel et al. 1999; Harwood et al. 1999; Gunasena and Roshetko 2000).

When clear land tenure exists, experience indicates that the development of smallholder agroforestry systems can be facilitated by focusing on three key issues – access to quality germplasm of appropriate species; enhancement of agroforestry system management skills; and the development of market linkages.

Quality germplasm of appropriate species is an important innovation and intervention, particularly for smallholders farming marginal lands, who have low capacity to absorb high risk and few resource options (Cromwell et al. 1993; Simons et al. 1994). In Southeast Asia quality tree 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. This should include developing farmers' tree propagation and tree nursery management skills. Training and participatory nursery development are proven methods of building farmers awareness, leadership and technical skills; and independence regarding germplasm quality, production and management capacity (Koffa and Garrity 2001; W.M. Carandang, personal communication).

Most smallholder agroforestry systems are characterized by limited proactive management and planning. Spacing is irregular and species components often primarily the result of chance. Harvesting products is often the most common management activity, with minimal weeding to control herbaceous and woody competition. As a result, the quality and quantity of products may be far below the systems' potential. The productivity of most smallholder agroforestry systems can be improved by enhancing smallholder management skills. Key issues are likely to include: species selection/site matching; identifying tree farming systems that match farmers' land, labor and socioeconomic limitations – including annual crops, tree crops, intercropping and understorey cropping options; tree management options to produce high quality products; pest and disease management; and soil management. These efforts should seek to develop a range of deliberate management techniques for trees and systems that enable farmers to produce quality products for specific market opportunities. Participatory farmer demonstration trials are an effective tool to establish smallholder agroforestry systems and develop farmer agroforestry skills and innovations (Roshetko et al. 2005).

Smallholders generally have weak market linkages and poor access to market information (Hammett 1994; Arocena-Fransico et al. 1999). Working in the Philippines, 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 a vital criterion for project sites (Scherr 1999, 1995; Landell-Mills 2002). 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; identifying the market channels that are accessible to smallholder farmers; identifying the problems faced by producers (smallholders) and traders that hamper the utilization or development of market channels; and identifying opportunities for expanding smallholders' role to include some post-harvest activities (sorting, grading and semi-processing). Additional efforts can evaluate the possibly of developing farmer marketing associations to assume transportation, wholesaling or other mid-channel activities. However, such activities require a different set of resources, skills, and information that most farmers currently do not have. This step is not an easy progression and should be carefully evaluated before being pursued (Roshetko et al. 2005).

4. 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 C 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 other environmental service projects, tree-based development projects and timber out-grower schemes 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.

4.1. Integrated planning and project design

Smallholders' investment 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 (Predo 2002; Yuliyanti and Roshetko 2002; Tyynela et al. 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 (Bass et al. 2000; Desmond and Race 2002; Tyynela et al. 2002), 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.

4.2. 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 (Scherr 1995, 1999; Desmond and Race 2000; Predo 2002; Tomich et al. 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.

4.3. 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. An impartial 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 (Brown et al. 2000; Desmond and Race 2000; Mayers and Vermeulen 2002; Tyynela et al. 2002). 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; Desmond and Race 2002; Tyynela et al. 2002; Fikar 2003).

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) 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, 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. The additionality of such arrangements could be proved by showing how the smallholder-oriented projects are not likely to be successful without the additional funds and 'enabling conditions' provided through CDM funding. At COP-9 it was decided that public funding from Annex 1 countries could be used to support small scale afforestation and reforestation (AR) CDM project activities, as long as such funding did not result in a diversion of 'official development assistance (ODA)' (UNFCCC 2003b). What remains to be determined is how this decision will be implemented, particularly if support of activities which are indirectly related to AR CDM activities (such as capacity building or work to remove barriers the inhibit CDM implementation) constitute a diversion of ODA (Winrock-LMGC 2005). Under CDM rules the use of C payments and co-funding resources, including ODA, are flexible. They can be used to meet transaction costs or provide incentive to stakeholders. What combination of financial resources is required and how they are allocated to cover costs and incentives are best determined at the project level. 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.

4.4. 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 both products and services, such as biodiversity conservation and watershed protection. These 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 it is necessary 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.

4.5. ADDITIONALITY, BASELINES, LEAKAGE AND PERMANENCE

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. It might be argued that smallholder agroforestry systems are a recognized 'business as usual' practice that should be excluded from CDM-type projects. This would be inaccurate. There are 35×10^6 ha 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 most of these areas. Certainly a project that facilitates 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 a process of natural regeneration. This is likewise inaccurate, as many of these sites are prone to cyclical fires, which eliminates natural regeneration (Wibowo et al. 1997; Friday et al. 1999). Experience in Indonesia and the Philippines (Friday et al. 1999) and India (Saxena 1997; Poffenberger 2002) 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.

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. The disadvantage with this approach is that managers may choose methods that maximize C credits for their project, making comparison between projects difficult (Ellis 1999; Brown et al. 2000). Thus, there remains a need to develop a set of standard methods that are 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 large number 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, 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 where degraded lands are common.

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 (Brown 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 (Watson et al. 2000) and does not meet 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. The rotational establishment/harvesting system employed to yield a predictable volume of biomass, simultaneously maintains high C levels in plantations. During the terms of a stipulated period the C stocks in industrial forestry lands are reliably permanent. However, industrial forestry projects 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 (Bass et al. 2000; Smith and Scherr 2002), 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 or 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 20–50 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.

The modalities and procedures for AR CDM projects addresses the uncertain permanence of LULUCF activities by accounting for emissions reductions as temporary CER (tCER) or long term CER (lCER). A 'tCER' expires at the end of the commitment period following the one during which it was issued, while an 'lCER' expires at the end of the crediting period of the afforestation or reforestation project activity for which it was issued (UNFCCC 2004). Both tCERs and lCERs are likely to command lower prices then permanent CERs from the energy sector; the price for lCERs is likely to be higher then tCERs. One advantage of tCER is that farmers do not have to make long term commitments of their land as C sinks for CDM. Farmers can even harvest the trees once the tCERs have expired. On the other hand, lCERs require longer tree cover on farms with its attendant ecological benefits.

5. 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. Assuring that the landuse systems to be converted have not been 'forests', according to national definitions, since 31 December 1989 will assure that the resulting smallholder agroforestry systems satisfies existing CDM rules. Smallholder 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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Notes

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.
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.

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