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Chapter 13

Opportunities for linking climate change adaptation and mitigation through agroforestry systems

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Abstract

Agroforestry systems not only provide a great opportunity for sequestering carbon, and hence helping to mitigate climate change, but they also enhance the adaptive capacity of agricultural systems in tropical and subtropical regions. Agricultural research over the last few decades has been driven by the quest to increase the productivity and resilience of agricultural systems. While increasing productivity relates directly to the ability of a system to accumulate and retain carbon, improving the resilience of agricultural systems is largely the result of enhancing the capacity of such systems to cope with adverse climatic changes. This chapter presents data that examine the mitigation and adaptation potential of different agroforestry systems as well as their significance for income generation for rural populations. New areas of research are proposed and a better use of existing agricultural management knowledge is called for.

Introduction

Climate change will affect developing countries more severely because of their low capacity for adaptation (IPCC 2001). Within these countries, the agricultural sector is particularly vulnerable, putting rural populations at risk. Furthermore, climate change is an additional threat that might affect a country's ability to meet urgent rural development demands including the improvement of food security, poverty reduction, and provision of an adequate standard of living for growing populations. There is a real risk of losing the gains of the Green Revolution, which has largely eliminated the danger of famines such as those seen in the 1950s and 1960s. Several modelling studies carried out in South Asia to assess the impact of climate change (Aggarwal and Mall 2002; Aggarwal and Sinha 1993; Berge et al. 1997; Kropff et al. 1996; Rao and Sinha 1994; Saseendran et al. 2000) have shown that increases in temperature lead to a decrease in the length of the growing season and the yield of most crops. Maize production in the tropics is predicted to decline by 10 percent (Jones and Thornton 2003), with regions such as the Sahel and southern Africa suffering disproportionately.

Within the United Nations Framework Convention on Climate Change (UNFCCC) negotiation process, mitigation and adaptation activities have been largely dealt with as separate matters. Carbon sequestration through land use, land-use change and forestry (LULUCF) as a measure for mitigating climate change has been a very contentious issue during recent negotiations. However, agreements have been made on the modalities and procedures for LULUCF projects, which offer, inter alia, opportunities for agroforestry activities under the Clean Development Mechanism (CDM). Adaptation, on the other hand, was only recently recognized as an important and separate topic as expressed, for example, in the Delhi Declaration of the UNFCCC eighth session of the Conference of the Parties (COP 8) in 2002.

The discussion on the potential synergies between adaptation and mitigation measures is just starting and is all too often reduced to a discussion of the costs of global adaptation vs. global mitigation. A practical understanding of the link between adaptation and mitigation measures, particularly with respect to land use and land management, does not yet exist. Yet agricultural research in the last few decades has been addressing the need to cope with adverse and irregular climatic conditions including rainfall variability or shifting weather patterns. Similarly, there has been a major emphasis on improving the productivity of agricultural systems, leading to the understanding that increasing soil carbon stocks in degraded lands is essential for enhanced productivity. Agroforestry provides a unique opportunity to reconcile the objectives of mitigation of, and adaptation to, climate change.

Agroforestry and climate change mitigation

A wide range of studies (Albrecht and Kandji 2003; IPCC 2000; Palm et al. 2005) have substantiated the fact that agroforestry systems, even if they are not primarily designed for carbon sequestration, present a unique opportunity to increase carbon stocks in the terrestrial biosphere (Table 1). Worldwide it is estimated that 630 x 10^6 ha are suitable for agroforestry. Carbon is particularly useful in agricultural systems (Figure 1), making agroforestry a quantitatively important carbon sink.

Agroforestry systems in the humid tropics are part of a continuum of landscapes ranging from primary forests and managed forests to row crops or grasslands. They are mostly perennial systems such as homegardens and agroforests in which the tree component can stay in the field for more than 20 years. Agroforestry trees play important roles including shading tree crops such as cocoa, nutrient cycling and improving the microclimate. Since trees and crops grow at the same time, these systems are referred to as simultaneous systems. Figure 2 shows that converting primary tropical forests to agriculture or grassland results in a massive loss of carbon storage capacity. While agroforestry systems contain less carbon than primary or managed forests, the fact that they contain significantly higher carbon stocks than row crops or pastures suggests that the introduction and proper management of trees in crop lands has a great potential for carbon sequestration, in addition to rehabilitating degraded land.

Unlike simultaneous systems, improved fallows are tree–crop rotation systems whereby fast-growing, often leguminous, trees are cultivated for a period of 8 months to 3 years to enhance nutrient-depleted soils and degraded lands in the sub-humid tropics. Even in drier areas such as the Sudan–Sahel zone of West Africa, recent field experiments have shown that this technology could significantly contribute to curbing land degradation and improving farm productivity. Typically, improved fallows are short-term rotation systems and as such sequester much less carbon above ground than perennial systems. However, several studies on soil carbon dynamics have indicated that soil organic matter increases after a few seasons of tree planting on degraded soils. On-farm trials in the

Table 1. *Potential carbon (C) storage[1] for agroforestry systems in different ecoregions of the world.*

	Ecoregion	System	Mg C ha^{-1}
Africa	humid tropical high	agrosilvicutural	29–53
South America	humid tropical low dry lowlands	agrosilvicutural	39–102 39–195
Southeast Asia	humid tropical dry lowlands	agrosilvicutural	12–228 68–81
Australia	humid tropical low	silvopastoral	28–51
North America	humid tropical high	silvopastoral	133–154
	humid tropical low	silvopastoral	104–198
	dry lowlands	silvopastoral	90–175
Northern Asia	humid tropical low	silvopastoral	15–18

[1] Carbon storage values were standardized to a 50-year rotation.
Sources: Dixon et al. 1993; Krankina and Dixon 1994; Schroeder 1993; Winjum et al.1992).

sub-humid tropics of Togo and Kenya have shown various degrees of success depending on location (rainfall and soil type), fallow species, duration of the fallow phase and sampling depth; soil organic carbon accretions through employing improved fallow were estimated to be between 1.69 and 12.46 Mg ha^{-1} (Table 2).

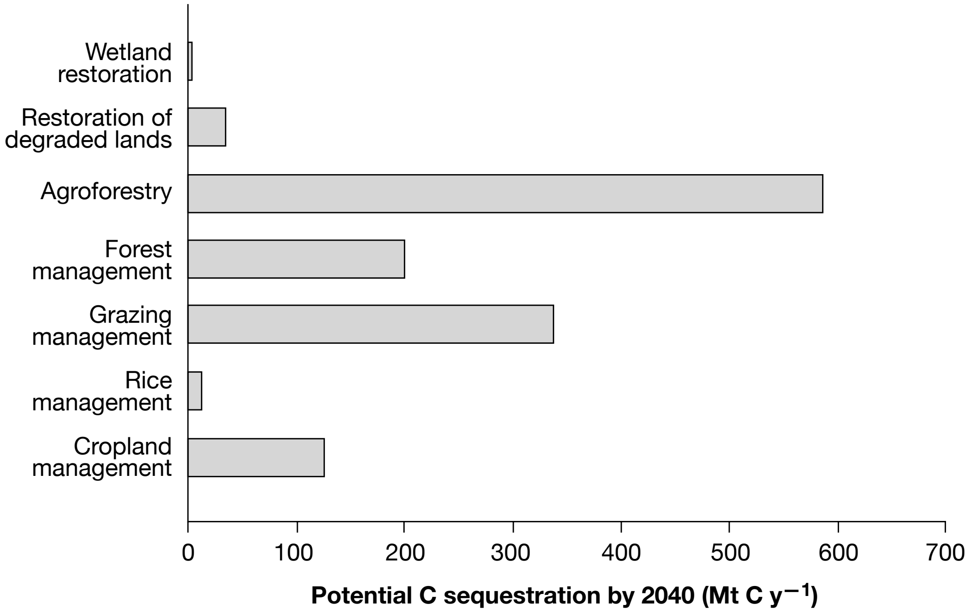

Figure 1. *Carbon (C) sequestration potential (in millions of tonnes per year) of different land use and management options.*

Source: IPCC (2000).

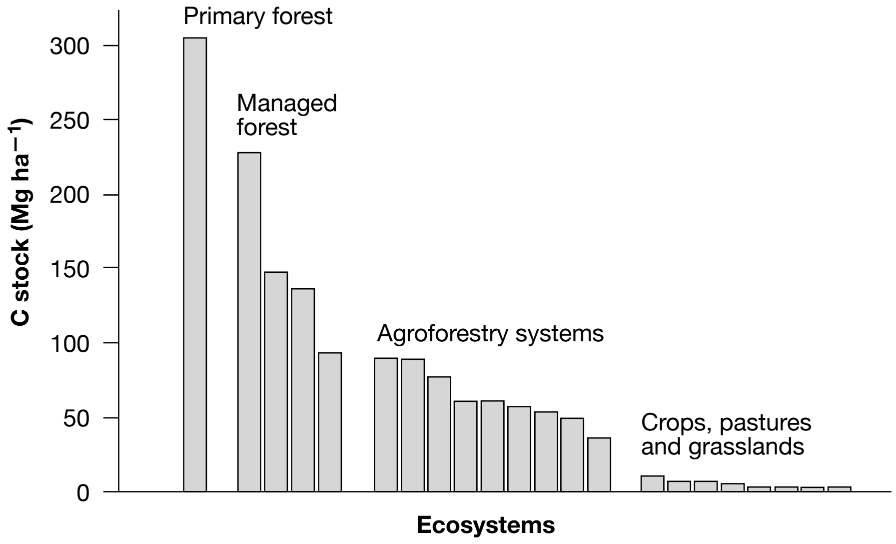

Figure 2. *Summary of carbon (C) stocks in different ecosystems of the humid tropics. Data are from the benchmark sites of the Alternatives to Slash and Burn (ASB) Programme of the Consultative Group on International Agricultural Research (CGIAR).*

Although carbon fluxes in agroforestry systems are well documented, we have a much poorer understanding of the effects of these practices on non-carbon dioxide (CO_2) greenhouse gases. In the case of nitrous oxide (N_2O) emissions, much depends on the presence or absence of legumes in the system. In general, agroforestry systems, which promote the use of legumes as fertilizer or shade trees, may increase N_2O emissions compared to unfertilized systems. Similarly, tree-based systems that encourage the introduction and development of livestock farming may contribute to increasing methane (CH_4) emissions. While efforts should be made to minimize the emission of these trace gases, what ultimately matters in terms of climate change mitigation is how these emissions compare to the amount of carbon sequestered in agroforestry systems. For example, in an improved fallow–maize rotation system in Zimbabwe, N_2O emissions were found to be almost 10 times those of continuous unfertilized maize (Chikowo et al. 2003), but these levels were still extremely low when compared to the increase in the amount of carbon stored.

Enhancing farmer adaptive capacity through agroforestry

As adaptation emerges as a science, the role of agroforestry in reducing the vulnerability of agricultural systems (and the rural communities that depend on them for their livelihood) to climate change or climate variability needs to be assessed more effectively. Rainfall variability is a major constraint in the semi-arid regions and to the upland farms in Southeast Asia that do not have access to irrigation. However, the effects of variable rainfall are often exacerbated by local environmental degradation. Therefore, curbing land degradation can play an important role in mitigating the negative impacts of climate change and

Table 2. *Soil organic carbon (SOC) increase over the duration of the fallow phase in a few tropical soils with different tree species in the sub-humid tropics.*

Country	**Fallow duration** (years)	**Soil type**	**Fallow species**	**Sampling depth** (cm)	**SOC increase** **Total** (Mg ha^{-1})	**SOC increase** **Annual** (Mg ha^{-1} yr^{-1})
Togo	5	Ferric Acrisol (sandy)	*Acacia auriculiformis* *Albizzia lebbeck* *Azadirachta indica* *Cassia siamea*	0–10	3.41–12.46	0.68–2.49
Kenya	1.5	Arenosol (sandy)	*Crotalaria grahamiana* *C. paulina*	0–20	1.69–2.15	1.13–1.43
Kenya	1.5	Ferralsol (clayey)	*Crotalaria grahamiana* *C. paulina* *Tephrosia vogelii*	0–20	2.58–3.74	1.72–2.49

Source: Albrecht and Kandji (2003).

variability, and that is where agroforestry can be a relevant practice.

Successful and well-managed integration of trees on farms and in agricultural landscapes often results in diversified and sustainable crop production, in addition to providing a wide range of environmental benefits such as erosion control and watershed services. In western Kenya, the World Agroforestry Centre, together with various partners, has tested the potential of improved fallow systems for controlling soil erosion, using fast-growing shrubs such as *Crotalaria* spp. and *Tephrosia* spp. These species showed great promise in reducing soil losses (Boye and Albrecht 2005). At the same time a significant improvement in soil water storage has been observed in the improved fallow systems (Figure 3). We now understand that climate change may translate into reduced total rainfall or increased occurrence of dry spells during rainy seasons in many semi-arid regions. Therefore, optimizing the use of increasingly scarce rainwater through agroforestry practices such as improved fallow could be one way of effectively improving the capacity of farmers to adapt to drier and more variable conditions.

Under many of the different farmer practices in Africa, crops will still fail completely or yield very little in drought years. Results from improved fallow trials were used to model these various systems. The model suggested that it would be possible to produce an acceptable amount of food in low rainfall years if practices such as improved fallows were pursued (Table 3). As expected, maize production was higher after improved fallow than in a continuous cropping system in good rainfall years (typically 962–1017 mm of rain). A similar trend was observed in low rainfall years (< 600 mm). Most interestingly, the model predicted that maize yield in a low rainfall year after a *Sesbania* spp. fallow period was even higher than maize yield in the continuous cropping system in a good rainfall year. If we define rainfall use efficiency (RUE) as the amount of maize (in kg) produced with each mm of rainwater, then, apparently, the maize crop after improved fallow made better use of the available water than the continuous crop, especially when rainfall was low (Table 3). In low-rainfall years, water availability to crops is paramount and seems to be the dividing factor between absolute crop failure and reasonable food production. Buffering agricultural crops against water deficiencies is, therefore, an important function agroforestry would have to play in the adaptation battle.

There are other mechanisms such as improved microclimate and reduced evapotranspiration through which agroforestry practices may improve the adaptive capacity of farmers. In the African drylands, where climate variability is commonplace, farmers have learned to appreciate the role of trees in buffering against production

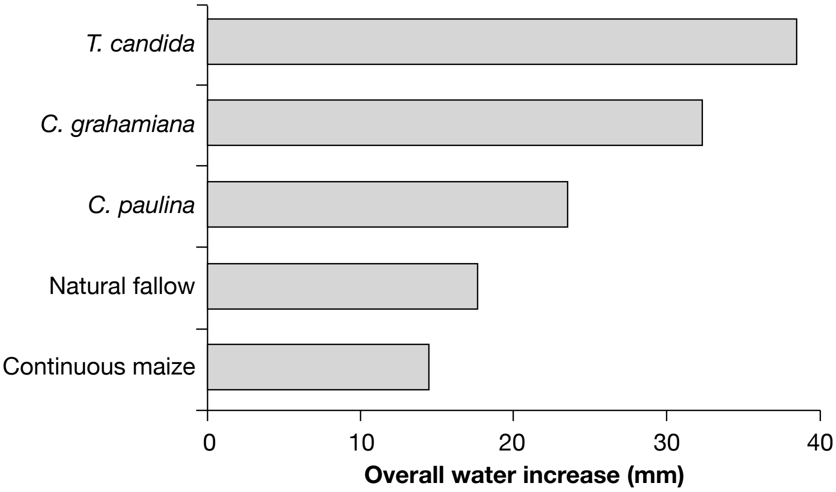

Figure 3. *Change in soil water stocks (0–60 cm depth) in a western Kenyan soil under continuous maize, natural fallow and improved fallow systems using either* Tephrosia candida*,* Crotalaria grahamiana *or* Crotalaria paulina.

Source: Orindi (2002).

risk (Ong and Leakey 1999). The parkland farming system, in which trees are encouraged to grow in a scattered distribution on agricultural land, is one example. One of the most valued (and probably most intriguing) trees in the Sahel is *Faidherbia albida*. Thanks to its reversed phenology (the tree sheds its leaves during the rainy season), *F. albida* significantly contributes to maintaining crop yield through biological nitrogen fixation and provision of a favourable microclimate while minimizing tree–crop competition. A study on an *F. albida*–millet parkland system in Niger demonstrated that shade-induced reduction of soil temperatures, particularly at the time of crop establishment, is critical for good millet growth (Vandenbeldt and Williams 1992).

This type of reversed phenology is not observed in other parkland trees such as the shea butter tree (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*), which have a negative shading effect that may reduce millet yield under the tree by 50 to 80 percent in some cases (Kater et al. 1992). Farmers are well aware of this loss in yield, but do not mind it since the economic benefits from harvesting marketable tree products largely compensate for the loss of crop yield. However, in extremely hot conditions (which we may have to face in the future), the shading effect of these evergreen trees could compensate for the yield losses due to excess heat in the open areas of the field. Such a hypothesis has been validated by the work of Jonsson et al. (1999), who measured variables including temperature, photosynthetically active radiation (PAR is the light in the 400–700 nm waveband of the electromagnetic spectrum that is useful for photosynthesis) and millet biomass under and away from tree canopies in a parkland system (Table 4). The results showed that despite the heavy shading, similar amounts of millet biomass were obtained from the areas under these trees and in the open. This absence of yield penalty under trees was, to a great extent, explained by the fact that millet seedlings under tree canopies experienced only 1–9 hours per week of supra-optimal temperatures (> 40°C) compared with 27 hours per week in the open. In other words, the shorter exposure to extreme temperatures compensated for the millet biomass loss that would otherwise have occurred as a result of shading. This underscores the important role trees could

Table 3. *Grain yield (kg ha^{-1}) and rainfall use efficiency (RUE, kg mm^{-1}) of maize in continuous maize and improved fallow (IF;* Sesbania sesban*) systems across five seasons in Makoka, Zambia.*

	Season 1 (rainfall = 1001 mm)		**Season 2** (1017 mm)		**Season 3** (551 mm)		**Season 4** (962 mm)		**Season 5** (522 mm)	
	Maize	IF	Maize	IF	Maize	IF	Maize	IF	Maize	IF
Grain yield	990	1100	1300	2400	600	1850	1100	2300	500	1180
RUE	0.99	1.10	1.28	2.36	1.09	3.36	1.14	2.39	0.96	2.26

Table 4. *Mean temperature (T), duration when temperature exceeds 40°C (H40), photosynthetically active radiation (PAR) and millet biomass harvested under and away from the tree canopies. (Standard errors in parentheses).*

Treatment	T (°C)	H40 (h week^{-1})	PAR (µE m^{-2} s^{-1})	Millet biomass (g dry weight plant^{-1})
V. paradoxa (large)	–	–	429 (57)	46.2 (16.5)
V. paradoxa (small)	29.10 (0.3)	1	541 (64)	43.3 (17.5)
P. biglobosa (large)	28.30 (0.5)	9	451 (57)	56.2 (14.6)
P. biglobosa (small)	27.00 (0.3)	5	660 (45)	36.8 (14.3)
Control[1]	29.98 (0.4)	27	2158 (40)	39.8 (15.2)

[1] Control plots away from tree canopies.
Source: Jonsson et al. (1999).

play in mitigating the negative effects of extreme temperatures on crops, especially in semi-arid regions.

Pests, diseases and weeds already stand as major obstacles to crop production in many tropical agroecosystems and there are strong reasons to believe that their prevalence and deleterious effects on crops may increase with a warmer climate (Beresford and Fullerton 1989; Hill and Dymock 1989; Rosenzweig et al. 2000). It is strongly believed (Altieri and Letourneau 1982; Speight 1983), yet not sufficiently tested, that enhancing plant biodiversity and mixing tree and herbaceous species in agricultural landscapes can produce positive interactions that could contribute towards controlling pest and disease outbreaks. The potential of agroforestry to control both ordinary weeds (Gallagher et al. 1999; Impala 2001) and parasitic weeds such as *Striga hermonthica* (Rao and Gacheru 1998) has also been demonstrated.

Income generation through tree products

Besides the biophysical resilience, which allows the various components of the agroforestry systems to withstand shocks related to climate variability, the presence of trees in agricultural croplands can provide farmers with alternative or additional sources of income, so strengthening the socioeconomic resilience of rural populations. Tree products (including timber, fodder, resins and fruits) are normally of higher value than maize or hard grains such as millet and sorghum, and can buffer against income risks in cases of crop failure.

The Sahelian Eco-Farm (SEF) provides an eloquent example of how an agroforestry-based integrated natural resource management regime can help improve the livelihood of the rural poor in vulnerable regions such as the Sahel (Pasternak et al. 2005). The SEF is an integrated land-use system that incorporates high-value multipurpose trees/shrubs with soil and water conservation structures. The value produced is in the form of food, fuelwood and forage (which can all be converted into cash), plant nutrients, biomass for mulch (which contributes to increased infiltration of rainfall, and addition of organic matter to the soil), and protection from wind erosion. The first on-station test of the SEF took place at the Sahelian Center of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in Niger during 2002. The estimated income from a 1-ha farm was US$600, some 12 times the value of a typical millet crop (Table 5). The estimated costs of establishing the SEF are not high; the plant material costs about US$60 per ha, and the one-time application of fertilizer about US$10. The labour requirements for land preparation and tree planting are met by farmers and their families.

In the semi-arid zone of Kenya, the parkland system is showing similar success. The fast-growing indigenous species *Melia volkensii* is highly compatible with crops and can provide high-value timber in 5–10 years (Stewart and Blomley 1994). A study by Ong et al. (2002) in the Kitui district of Kenya showed that in an 11-year rotation period, the accumulated income from tree products exceeds the accumulated value of crop yield lost through competition. This income difference is worth US$10 or 42 percent during average years, and US$22 or 180 percent if a 50 percent rate of crop failure owing to drought (reasonable for Kitui) is assumed. In such a hostile environment, where crops normally fail every other year, good and secure financial returns from *M. volkensii* even in drought years can provide significant relief for farmers. This will be all the more necessary as extreme climate events (droughts and floods) are likely to increase in frequency and in magnitude in the near future.

Conclusions

The impact of climate change will be felt on several levels in the agricultural sector. Most of the effects will hit the rural poor in developing countries, who are the most vulnerable because of their poor ability to adapt. The adaptive capacity of farmers in developing countries is severely restricted

Table 5. *Value of Sahelian Eco-Farm (SEF) products from SEF–ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) Sadoré station during 2002.*

Species	**Quantity per unit area**	**Yield per unit**	**Unit value** (US$)	**Total revenue** (US$ ha^{-1})
Acacia colei	320 trees ha^{-1}	2 kg seeds tree	0.14 kg^{-1}	90
Zizyphus mauritiana	63 trees ha^{-1}	30 kg fresh fruit tree^{-1}	0.12 kg^{-1}	225
Andropogon gayanus	567 metres ha^{-1}	1 bundle 10m	0.8 bundle^{-1}	45
Millet	1/3 ha	1500 kg ha^{-1}	0.1 kg^{-1}	50
Cowpea	1/3 ha	1260 kg ha^{-1}	0.2 kg^{-1}	84
Roselle	1/3 ha	400 kg ha^{-1}	0.8 kg^{-1}	106
Total	1 ha			600

Source: Pasternak et al. (2005).

by their heavy reliance on natural factors and a lack of complementary inputs and institutional support systems.

The concepts of resilience and sustainable productivity are well established in agriculture and can be linked directly to the discussions about adaptation to and mitigation of climate change. Thus, policy makers can draw upon a substantial body of knowledge in this respect. However, the adaptation and mitigation synergies of agroforestry management systems warrant further investigation.

Within international fora, there is much talk about bringing adaptation into the mainstream of planning processes. We have shown above, through the specific case of agroforestry, that some mitigation measures simultaneously provide opportunities to increase the resilience of agricultural systems. It is suggested that such synergies ought to be promoted more intensively through the channels of the UNFCCC such as the CDM. However, if agroforestry is to be used in carbon sequestration schemes including the CDM, several areas need to improve, for example, we need better methods of assessing carbon stocks and non-CO_2 emissions. Furthermore, the debate on durable wood products is ongoing, but what is known is that farmers will need provisions to allow them to market wood products from their agroforestry systems, and we should develop methods to account for the lifetime of the carbon sequestered in agroforestry products. As small-scale farmers are enrolled in carbon-offset projects, we will need to develop a better understanding of the implications of these for carbon sequestration by agroforestry and what it means to livelihoods. Finally, the CDM has very stringent rules for participation that may be beyond the reach of small-scale farmers to understand or to provide evidence of compliance. There is a need for institutional support by national, regional and international centres of excellence to facilitate effective participation of small-scale farmers in the CDM.

In their attempts to develop adaptation strategies for the agricultural sector, scientists and policy makers must consider the complex interactions of constraints created by changing climates in the light of other stress factors. Government and international support in terms of research, education, and extension will be required to help farmers in developing countries cope with the additional stresses created by climate change and increased climate variability. Agroforestry can very likely contribute to increasing the resilience of tropical farming systems. However, our understanding of the potential of agroforestry to contribute to adaptation to climate change is rudimentary at best. Better information is required on the role of agroforestry in buffering against floods and droughts from both the biophysical (e.g. hydraulic lift or soil fertility) and financial (e.g. diversification and income risk) points of view.

Agroforestry promises to create synergies between efforts to mitigate climate change and efforts to help vulnerable populations adapt to the negative consequences of climate change. The research agenda in this area is fairly well defined; much is already known and putting these ideas into practice on the ground with small-scale farmers will allow us to learn important lessons.

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