Opportunities for linking adaptation and mitigation in agroforestry systems

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1. Introduction

There is increasing acceptance that even very ambitious climate change mitigation measures, which would go beyond the current international climate agreements, would not be sufficiently effective to halt the increase of atmospheric greenhouse gas concentrations in the medium term and that therefore adaptation measures are as needed as mitigation measures.

The impact of climate change will be affecting developing countries more severely than developed countries not the least because of their generally low adaptive capacities (IPCC, 2003). In these countries, the agricultural sector will be among the most vulnerable putting rural populations at large risks. At the same time, we recognise that climate change is yet an additional threat to urgent rural development demands including food security improvement, poverty reduction and provision of an adequate standard of living for growing populations. Much effort will be needed to integrate what is known about climate change response measures into national development planning (Abeygunawardena *et al.*, 2003).

Within the UN Framework Convention on Climate Change (UNFCCC) negotiation process, the development of mitigation and adaptation activities has been dealt with largely as separate matters (see Forner, this volume). 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 international climate negotiations. However, agreements have been made on the modalities and procedures for LULUCF climate projects, which offer, *inter alia*, opportunities for agroforestry activities under the Clean Development Mechanism (CDM). Adaptation, on the other side, was only recently given more recognition as an important and self-standing topic as expressed, for instance, in the 'Delhi Ministerial Declaration on Climate Change and Sustainable Development' of UNFCCC COP-8 in 2002.

The discussion on the potential synergies between adaptation and mitigation measures is therefore just only starting and the debate is all too often for political reasons reduced to a discussion of the costs of global adaptation versus global mitigation. A practical understanding of the link between adaptation and mitigation measures particular in LULUCF does not yet exist.

However, research in the agricultural sector has focused for some decades now on the need to cope with adverse and irregular climatic conditions including rainfall variability or shifting weather patterns, in particular in the world's arid and semi-arid areas. Equally, years of agricultural research have focused on improving the productivity of agricultural systems leading to the understanding that increasing, for instance, soil carbon stocks is essential for an enhanced productivity.

2. Expected climate change impacts on resilience and productivity of agro-ecosystems

Climate change will add additional stress to an already overtaxed system. The risk of losing the gains of the Green Revolution, which has largely eliminated the famines of the 1950s and 1960s, is real. Populations of developing countries, particularly in South Asia and sub-Saharan Africa, continue to grow at high rates, while the extent of harvested areas has stagnated or is decreasing in many grain producing areas of the world (Mann, 1997). To feed everyone adequately, world food production will have to double within the next 30 years (Cleaver and Schreiber, 1994). But, the shortfall in domestic cereal production in the developing world is expected to widen from around than 100 million tons in 1997 to around 190 million tons in the year 2020 (Rosegrant *et al.*, 2001). In many regions of the world, there will be a limited ability for new varieties and increased fertilizer use to further increase yields (Huang *et al.*, 2002). On top of this, degradation of soil and water resources has reached alarming proportions (Vasil, 1998; Smaling *et al.*, 1997) and will undermine future efforts to boost agricultural productivity.

Several modelling studies that combine spatial analysis with an analysis of the physiological effects of changes in carbon dioxide (CO_2), rainfall and temperature have been done in South Asia to assess the impact of climate change on crop production (Aggarwal and Sinha, 1993; Rao and Sinha, 1994; Kropff *et al*., 1996; Berge *et al*., 1997; Saseendran *et al*., 2000; Aggarwal and Mall, 2002). These studies have shown a decrease in the growing season and yield of most crops as temperature increases. Such reductions were only partially offset by a positive response to increased CO_2 concentrations.

An analysis of maize production in the tropics by Jones and Thornton (2003) suggests that maize production in the tropics will decline by 10% on average. However, this figures masks large variations. For example, the Sahel and southern Africa regions are likely to suffer disproportionately, while the East Africa highlands are likely to enjoy increased productivity.

Climate change will have also a direct effect on water storage, putting increased stress on water availability for irrigation. Furthermore diseases and insect populations are strongly dependent upon temperature and humidity, and changes could alter their distributions and virulence.

3. Agroforestry and climate change mitigation

A wide range of studies (IPCC, 2000; Albrecht and Kandji, 2003; Palm *et al*., 2005) have substantiated the fact that agroforestry systems, even if not primarily designed for carbon sequestration, present a unique opportunity to increase carbon stocks in the terrestrial biosphere (Table 1). The quantitative importance of agroforestry as carbon sink derives from wide applicability in existing agricultural systems. Worldwide it is estimated that 630 x 10^6 hectares are suitable for agroforestry (see also Figure 1).

Table 1. Potential carbon storage for agroforestry systems in different eco-regions of the world (Winjum *et al*., 1992; Dixon *et al*., 1993; Schroeder, 1993; Krankina and Dixon, 1994; Albrecht and Kandji, 2003)

	Eco-region	**System**	**Mg C ha^{-1}**
Africa	humid tropical high	agrosilvicutural	29–53
South America	humid tropical low	agrosilvicutural	39–102[a]
	dry lowlands		39–195
Southeast Asia	humid tropical	agrosilvicutural	12–228
	dry lowlands		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

[a] Carbon storage values were standardised to 50-year rotation.

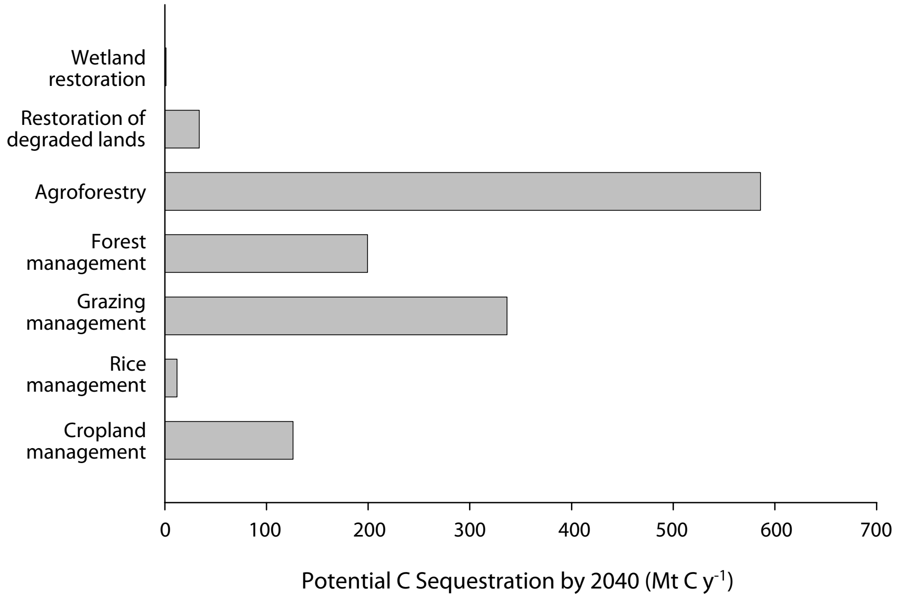

Figure 1. Carbon sequestration potential of different land use and management options (adapted from IPCC, 2000)

Agroforestry practices in the humid tropics are part of a continuum of landscapes ranging from primary forests and managed forests to row crops or grasslands. Figure 2 compares carbon storage in some land-use systems along this continuum. Using the time-averaged method (rotational agroforestry systems are characterised by a succession of harvest and regrowth periods), it has been shown that the conversion of primary tropical forests to agriculture or grassland results in the loss of about 370 Mg of carbon per hectare. Managed or logged forests have about half the carbon stocks of primary forests. Agroforestry systems contain 50 to 75 Mg of carbon per hectare compared to row crops that contain less than 10 Mg of carbon per hectare. The difference in carbon content between both systems indicates the mentioned potential for agroforestry systems to store additional carbon, however, possible tradeoffs between carbon storage and profitability in agroforestry systems have to be taken into account (Gockowski *et al*., 2001). As shown in Figure 3, land-use systems that maximise both carbon and profit (win-win options) are not realistic. Therefore, climate change mitigation through agroforestry should be based on the promotion of no-regret or win-win options, which would allow medium to high profit while storing an acceptable, rather than a maximum level of carbon in the system.

Distinct from simultaneous crop-tree systems are improved fallow systems that improve nutrient depleted soils and otherwise degraded land. Improved fallow is undoubtedly one of the most promising agroforestry technologies in the sub-humid tropics and has, in recent years, shown great potential for adoption in southern and eastern Africa. Even in drier areas such as the Sudan-

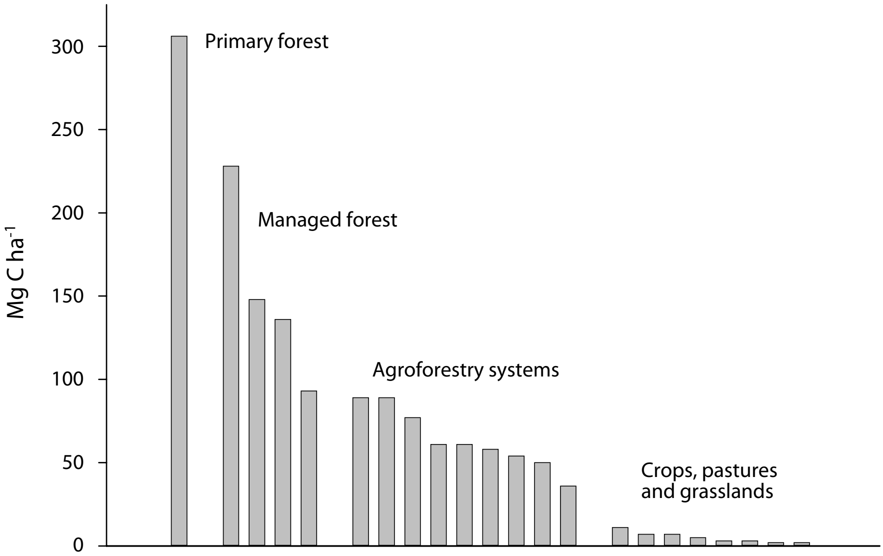

Figure 2. Summary of carbon stocks in different ecosystems of the humid tropics. Data are from the benchmark sites of the Alternatives to Slash and Burn Programme of the Consultative Group for International Agricultural Research (CGIAR)

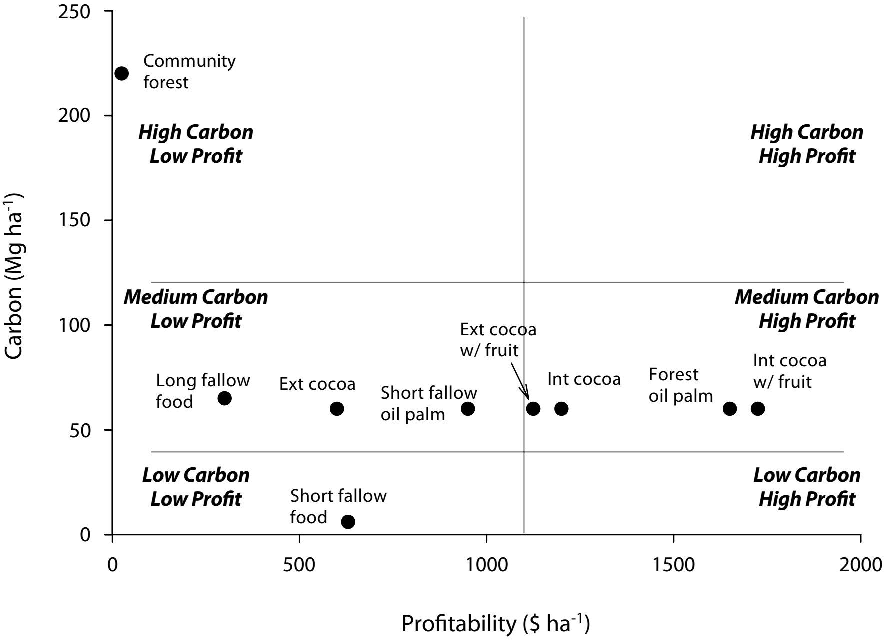

Figure 3. Tradeoffs between carbon stocks and social profitability of land use systems in Cameroon (adapted from Gokowski *et al.*, 2001)

Sahel zone of West Africa, recent field experiments have shown that the technology could significantly contribute to curbing land degradation and improving farm productivity. Unlike the more perennial systems in the humid tropics, improved fallows are mostly short-rotation and as such sequester much less carbon aboveground. Nevertheless, if the time-averaged aboveground carbon is considered, they store substantial quantities of carbon compared to degraded land, croplands or pastures (Table 2).

Table 2. Carbon stocks (Mg ha^{-1}) in improved fallow systems (adapted from Albrecht and Kandji, 2003, and assuming that biomass is 47% C)[b]

Fallow species	Aboveground	Belowground	C in fine root	Total C
12-month-old fallows				
Crotolaria grahamiana	4.0	1.3	–	5.3
Calliandra calothyrsus	9.9	3.3	–	13.2
Cajanus cajan	4.0	1.8	–	5.8
Senna spectabilis	3.3	2.3	–	5.5
Sesbania sesban	6.7	3.4	–	10.1
Tephrosia vogelii	5.1	1.9	–	7.0
18-month-old fallows				
Crotalaria grahamiana	11.6	5.1	3.0	19.7
Crotolaria paulina	9.3	6.4	1.7	17.4
Tephrosia candida	14.6	15.6	1.7	31.9
22-month-old fallows				
Calliandra calothyrsus	12.7	7.3	1.3	21.3
Sesbania sesban	17.3	5.1	1.1	23.5
Grevillia robusta	15.3	8.3	1.3	25.0
Eucalyptus saligna	20.4	9.0	1.1	30.5

[b] Soil C was not included in the calculation of C stocks.

Several studies on soil carbon dynamics have indicated increased soil organic matter after a few seasons of tree planting on degraded soils. The examples used in Table 3 mainly come from on-farm trials conducted in the sub-humid tropics of Togo and Kenya. A wide range of tree species have been tested with various degrees of success. Soil organic carbon accretions through improved fallow were estimated between 0.73-12.46 Mg per hectare depending on sampling depth.

If carbon fluxes in agroforestry systems are well documented, we have a much poorer understanding of the effects of these improved practices on non-CO_2 greenhouse gases. In the case of nitrous oxide (N_2O) emissions, much depends on the presence or absence of legumes in agroforestry system. For example in Sumatra, a jungle rubber system was shown to have lower N_2O emissions compared to a primary forest, but also lower methane (CH_4) uptake (Tsuruta *et al.*, 2000). However, the relationship might be different in agroforestry systems that include nitrogen-fixing species. For example, multi-story coffee with a leguminous tree shade canopy in Sumatra had N_2O emissions five times

Table 3. Soil organic carbon (SOC) increase in a few tropical soils following improved fallows with different tree species in the sub-humid tropics

Country	Fallow duration (years)	Soil type	Fallow species	Sampling depth	SOC increase (Mg ha^{-1})
Togo	5	Ferric Acrisol (sandy)	*Acacia auriculiformis, Albizzia lebbek, Azadirachta indica, Cassia siamea*	0-10 cm	3.41 – 12.46
Kenya	1.5	Arenosol (sandy)	*Crotalaria grahamiana, C. paulina*	0-20 cm	1.69 – 2.15
Kenya	1.5	Ferralsol (clayey)	*C. grahamiana, C. paulina, Tephrosia vogelii*	0-20 cm	2.58 – 3.74
Kenya	1	Ferralsol (clayey)	*Cajanus cajan, Leucaena leucocephala, Sesbania sesban*	0-30 cm	0.73 – 8.34

higher than open-grown coffee and about half the CH_4 uptake (Verchot *et al.*, unpublished data). In Peru, agroforestry systems (multi-strata coffee and a peach palm plantation) with leguminous cover crops had lower N_2O emissions than both intensive and low-input agriculture, and similar emissions to a nearby secondary forest (Palm *et al.*, 2002). Soil uptake of CH_4 was similar to other land-use systems, with the exception of the intensive agriculture site, which became a net source to the atmosphere.

It is apparent from the case studies above that the 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 CH_4 emissions. While efforts should be made to minimise 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 these agroforestry systems. For example, in an improved fallow system in Zimbabwe, N_2O emissions were found to be almost 10 times those of unfertilized maize (Chikowo *et al.*, 2003), but these levels were still extremely low in comparison to the amount of carbon stored. Therefore, despite the likelihood of accrued trace gas emissions in some cases, most agroforestry systems are likely to be net greenhouse gas sinks because of the important amount of carbon they can store in the living plant biomass, in the soil and in durable wood products.

It is also worth to note that the financial cost of carbon sequestration through agroforestry appear to be much lower (approximately $1–69/Mg of carbon, median $13/Mg of carbon) than through other CO_2 mitigating options. Economic analyses showed that these costs could be easily offset by the monetary benefits from agricultural and tree products.

Beyond the apparent mitigation effects of agroforestry systems as outlined above, agroforestry offers a potential as biomass energy provider. Producing firewood from arable or grazed land presents interesting opportunities in CO_2 mitigation through the substitution of fossil energy consumption by using wood as energy sources and the protection of existing forests and other natural landscapes. Adequate understanding of these secondary effects of agroforestry with regards to CO_2 mitigation will require more research.

4. Enhancing adaptive capacity through agroforestry

The effects of different agroforestry techniques in enhancing the resilience of agricultural systems against adverse impacts of rainfall variability, shifting weather patterns, reduced water availability, soil erosion as well as pests, diseases and weeds is been well tested. Much of this knowledge is relevant for mainstreaming adaptation measures to climate change into the agricultural sector. As adaptation is yet developing as 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 should be more strongly emphasised.

Rainfall variability is a major cause of vulnerability in many areas of the tropics, especially in the semi-arid regions. However, its effects are often exacerbated by local environmental degradation. In reality, vulnerability in many of these fragile ecosystems is often the result of a degenerative process due a combination of factors (deforestation, continuous cropping and overgrazing), which, when associated with extreme climate, represents a major setback for agricultural and economic development. Therefore, curbing land degradation can play an important role in mitigating the negative impacts of climate change/variability, and that is where agroforestry can be a relevant practice.

A successful and well-managed integration of trees on farms and in agricultural landscapes inevitably results in diversified and sustainable crop production, in addition to providing a wide range of environmental benefits. Systems such as hedgerow intercropping and boundary plantings are effective in protecting soils from erosion and restoring some fertility in degraded lands. In western Kenya, the World Agroforestry Centre, in collaboration with the Institut de Recherche pour le Développement (IRD) and Kenyan national agricultural research services, has tested the potential of improved fallow for controlling soil erosion, using fast growing shrubs such as *Crotalaria grahamiana* and *Tephrosia spp*. These species showed great promise in reducing soil losses (Figure 4). Soil protection through improved fallow is a process that starts right from the fallow period when tree cover reduces soil battering by raindrops, but continues way

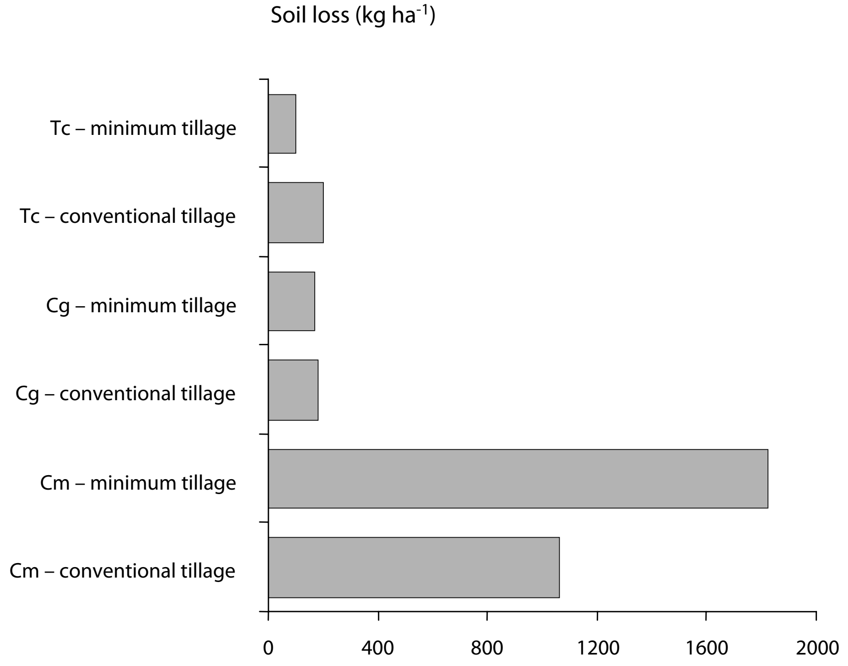

Figure 4. Effect of improved fallow on soil erosion in the long rains (March-July) of 2003, Luero, western Kenya (data from Boye, unpublished)

The total rainfall for the season was 871mm
Legend: Cm = continuous maize; Cg = Crotalaria grahamiana; Tc = Tephrosia candida

NB: Soil loss is resultant of both runoff and turbidity (the solid load of the runoff water). The substantial decrease in soil loss due to improved fallow (nine times less than continuous cropping) is explained by the fact that : (1) runoff was higher and therefore infiltration lower in the continuous crop situation and (2) turbidity was higher in the continuous crop situation than in the improved fallows.

after fallow clearance thanks to the improvement of soil structure (increased soil organic matter, formation of water-stable aggregates, better soil cohesion and aeration, and improved water infiltration).

Improved infiltration of water, while reducing runoff and transportation of sediments, also has a direct effect on water storage in the soil. Studies on water dynamics in a maize field in western Kenya showed that, after a rainfall event, soil moisture accumulates much faster under improved fallow than under maize crop and natural fallow. In addition, the improvement of the soil structure and the soil organic matter allows the water to be stored much longer in the improved systems than in the continuous maize during a dry period (Figure 5). The implication is tremendous from an agronomic point of view. If rainfall is scarce, then crops that follow an improved fallow are likely to have a better water supply than those which follow another crop. We now understand that climate change in many areas, especially in semi-arid regions, will translate into

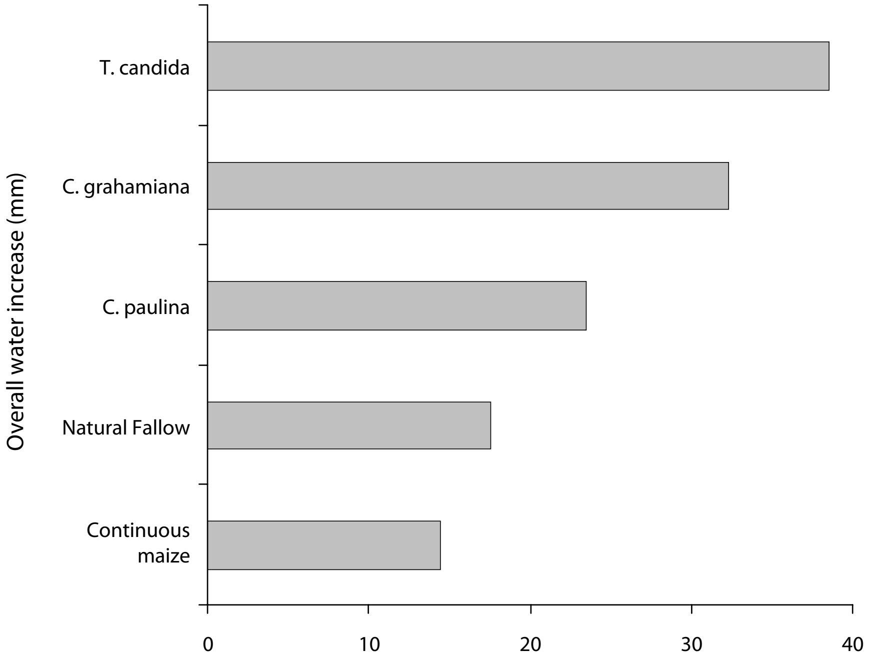

Figure 5. Change in soil water stocks (0–60 cm depth) in a western Kenyan soil under continuous maize, natural fallow and improved fallow systems (data from Orindi, 2002)

a reduced total rainfall or an increased occurrence of dry spells during rainy seasons. Therefore, optimising the use of increasingly scarce rainwater through agroforestry practices such as improved fallow could be one effective way of improving the adaptive capacity of systems to climate change.

Under many farmer practices in Africa, crops fail completely or yield very little in drought years. Yet, recent results from improved trials suggest that it would be possible to produce an acceptable amount of food in low rainfall years if practices such as improved fallows were pursued. Such a scenario was observed in an experiment in Malawi (Table 4). As expected, maize production was higher after improved fallow than in a continuous cropping system in good rainfall years (962–1017 mm). A similar trend was observed in low rainfall years (< 600 mm). More interestingly, maize yield after *Sesbania sesban* in a low rainfall year was even higher than maize yield in the continuous cropping in a good rainfall year. If we use rainfall use efficiency (RUE) as the amount of maize (in kg) produced with each millimetre of rainwater, then apparently, the maize crop after improved fallow made better use of rainfall than the continuous crop, especially in low rainfall years (Table 4).

The fact that improved fallows have the ability to maintain yields under adequate water supply is nothing new and indeed has been widely linked to an improvement in the physical, chemical and biological properties of soils. In low rainfall years, however, water availability 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 that agroforestry would have to play in the adaptation battle, but there are also other mechanisms such as improved micro-climate and reduced evapotranspiration through which agroforestry practices may improve the adaptive capacity of agroecosystems in the occurrence of extreme climate. For example, a study on a *Faidherbia albida* – millet parkland system in Niger demonstrated that shade-induced reduction of soil temperatures, particularly at the time of crop establishment, contributes to the better growth of millet under trees (Vandenbeldt and Williams, 1992). Also, Jonsson *et al.* (1999) measured temperatures, photosynthetically active radiation (PAR) and millet biomass under and away from tree canopies in a parkland system. The results showed that despite the heavy shading by Shea butter tree (*Vitellaria paradoxa*), known in the Sahel as karité and *Parkia biglobosa* (or néré), millet biomass was similar under these trees and the open plots away from tree canopy (Table 5). The absence of yield penalty under trees is explained by the fact that millet seedlings under tree canopies experienced only 1–9 hours per week of supra-

Table 4. Grain yield (kg ha^{-1}) and rainfall use efficiency (RUE) of maize in continuous maize and improved fallow (*Sesbania sesban*) systems in Makoka, Zambia

	Season 1 (1001mm)		**Season 2 (1017mm)**		**Season 3 (551mm)**		**Season 4 (962mm)**		**Season 5 (522mm)**	
	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 5. Mean temperature (T), thermal time (θ), 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; source Jonsson *et al.*, 1999)

Treatment	**T (°C)**	**θ (°C d)**	**H40 (h/week)**	**PAR (μE m^{-2} s^{-1})**	**Millet biomass (g dry weight/ plant)**
karité (large)	–	–	–	429 (57)	46.2 (16.5)
karité (small)	29.1 (0.3)	19	1	541 (64)	43.3 (17.5)
néré (large)	28.3 (0.5)	18	9	451 (57)	56.2 (14.6)
néré (small)	27.0 (0.3)	17	5	660 (45)	36.8 (14.3)
Control[c]	29.98 (0.4)	2	27	2158 (40)	39.8 (15.2)

[c] Control plots away from tree canopies.

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, which would otherwise have occurred as result of shading. This underscores the important role trees could play in mitigating the negative effects of extreme temperatures on crops, especially in semi-arid areas.

Pests, diseases and weeds already stand as major obstacles to crop production in many tropical agro-ecosystems and there are strong reasons to believe that their prevalence and their deleterious effects on crops may increase with a warmer climate. It is strongly believed, yet not sufficiently tested, that enhancing plant biodiversity and mixing tree and herbaceous species in agricultural landscapes can produce positive interactions that could contribute to controlling pest and disease outbreak.

Weeds are one of the most serious limiting factors to tropical agriculture and their control has proved to be beyond the capacities of many smallholder farmers (Akobundu, 1991; Akobundu, 1993; Gallagher *et al.*, 1999). Following climate change scenarios weed pressure can be expected to become more serious in most parts of Africa. The most obvious mechanism of weed control through trees in agricultural systems is through competition for light (shading effect), water and nutrients (Impala, 2003). But there are other specific processes such as allelopathy, which have also been described in some of fallow trees (Gallagher *et al.*, 1999). In addition, some agroforestry trees are known to act as trap crops triggering the germination of the weed seeds without being suitable hosts. For example, *Sesbania sesban*, *Markhamia lutea* and *Leucaena diversifolia* have shown good potential in controlling *Striga hermonthica*, a parasitic weed that plague many cereal production systems in Africa (Oswald *et al.*, 1996; Rao and Gacheru, 1998).

5. Income generation through tree products

Beside the biophysical resilience, which allows the various components of the agroforestry systems to withstand the shocks related to climate variability, the presence of trees in agricultural croplands can provide farmers with alternative or additional sources of income thus strengthening the socio-economic resilience of rural populations.

Tree products (timber, fodder, resins and fruits) are normally of higher value compared to maize or hard grains such as millet and sorghum and can buffer against income risks in case of crop failure. Therefore, one of the major strengths of agroforestry systems is that they can significantly contribute to the objective of climate change mitigation (through carbon sequestration) while providing enough biophysical and economic flexibility and resilience to adapt to the negative effects of climate change or climate variability. 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, unpublished). The SEF is an integrated land-use system that incorporates high-value multipurpose trees/shrubs with soil and water conservation structures, which are in turn reinforced. The value produced is in the form of food, firewood, forage, 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 ICRISAT Sahelian Center in Niger during 2002. The estimated income from a one hectare farm was US$600, some 12 times the value of a typical millet crop (Table 6). The estimated costs of establishing the SEF are not high; the plant material costs about US$60 per hectare, and the one-time application of fertilizer is about US$10. The labour requirements for land preparation and tree planting are met by farmers and their families.

Table 6. Value of Sahelian Eco-Farm (SEF) products from SEF - ICRISAT Sadore station during 2002 (source Pasternak, unpublished)

Species	Quantity-area	Yield/ units	Unit Value (US$)	Forage Value	Fire-wood Value	Revenue (US$)
Acacia colei	320 trees/ ha	2 kg seeds/ tree	0.14/kg	None	?	90
Zizyphus mauritiana	63 trees/ha	30 kg fresh fruit/tree	0.14/kg	High	High	225
Andropogon gayanus	567 meters/ha	1 bundle/ 10m	0.8/bundle	Limited	None	45
Millet	1/3 ha	500 kg	0.1	Medium	Low	50
Cowpea	1/3 ha	420 kg	0.2	High	None	84
Roselle	1/3 ha	133 kg	0.8	High	Medium	106
Total	**1 ha**			**?**	**?**	**600**

The SEF appears to provide countless Sahelian farming households with a real opportunity to break the endemic regional cycle of poverty and environmental degradation. The strength of the Sahel Eco-Farm lies in the fact that it promotes crop diversification and system resilience by combining various species of trees or shrubs (*Acacia colei*, *Zizyphus mauritiana* also known as 'pomme du Sahel'), grass (*Andropogon gayanus*) and annual crops such as roselle (*Hibiscus sabdariffa*), a relatively high value crop with food crops (millet and cowpea).

The parkland or scattered-tree system is another important agroforestry system worth mentioning. In the drylands of Africa, where climate variability is commonplace and adverse impacts of climate change are expected, farmers have evolved to appreciate the role of trees in buffering against production risk (Ong and Leakey, 1999). For 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* contributes significantly to maintaining crop yield through biological nitrogen fixation and favourable micro-climate while minimising tree–crop competition. Furthermore, its protein-rich leaves, twigs and pods constitute a precious source of animal feed for livestock during the long dry seasons in the Sahel. This phenomenon of reversed phenology is not observed with other parkland trees such as shea butter tree (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*), whose negative shading effect may reduce millet yield under the tree by 50-80% in some cases (Kater *et al*., 1992). Farmers are well aware of this yield penalty, but do not mind it. In fact, they put a great value on these trees because the economic yields from marketable tree products compensate for the loss of crop yield.

Parklands are also gaining popularity in the semiarid zone of Kenya. However, unlike in the Sahel, where trees are often naturally established, here farmers plant the fast-growing indigenous species *Melia volkensii* (Meliaceae) in a more intensive arrangement. This tree is reputed to be highly compatible with crops and can provide high value timber in five to ten years (Stewart and Blomley, 1994). A study by Ong *et al.* (1999) in the Kitui district of Kenya showed that in a 11- year rotation, the accumulated income from tree products exceeds the accumulated value of crop yield lost through competition by US$10 or 42% during average years and US$22 or 180% with the assumption of 50% crop failure due to drought. 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 climate extremes are likely to increase in frequency and in magnitude in the near future.

6. Conclusions

Impacts of climate change will be felt on several levels in the agricultural sector: at the level of the individual crop species, at the farming system level (entire farm), and at the level of the natural resource base upon which rural communities depend. Preliminary vulnerability estimates may be too pessimistic for many agricultural systems with high adaptive capacity, but there clearly are limits to adaptation within agriculture. Impacts will be felt most by rural poor in developing countries, who are the most vulnerable because of their low adaptive capacity. The adaptive capacity of farmers in developing countries is severely restricted by heavy reliance on natural factors and 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 on how to enhance the adaptive capacity and mitigation potential of agricultural systems. The adaptation and mitigation synergies of agroforestry management systems are worth further and more focused research.

Within international fora, there is much talk about 'mainstreaming' adaptation into 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 also through the mechanisms of the UNFCCC such as the CDM.

However, if agroforestry is to be used in carbon sequestration schemes such as the CDM, better information is required in several areas. For example, we need better data on aboveground and belowground carbon stocks, and the non-CO_2 emissions of different agroforestry systems. Whereas agroforestry systems are primarily production systems, there will be periodic harvesting and marketing of wood products. The debate on durable wood products is ongoing, but provisions will be needed to allow farmers to market wood products from their agroforestry systems and accounting methods will be needed 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 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 an effective participation of small-scale farmers in the CDM.

In an effort to develop adaptation strategies for the agricultural sector, scientists and policymakers must consider the complex interactions of constraints created by changing climates in 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 (hydraulic lift, soil fertility) and financial (diversification, income risk) points of view.

Agroforestry offers the potential to develop 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. Yet, much is already known and putting these ideas into practice on the ground with small-scale farmers will allow us to learn important lessons through practical experience.

7. References

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