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# Soil carbon sequestration and the CDM

## Opportunities and challenges for Africa

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# Abstract

The agriculture sector dominates the economies of most sub-Saharan countries, contributing about one-third of the region's GDP, accounting for forty percent of the export, and employing about two-thirds of the economically active population. Moreover, some soils in sub-Saharan Africa could, by providing sinks for carbon sequestration, play an important role in managing global climate change. Improvements in agricultural techniques and land use practices could lead to higher agricultural productivity and accumulate soil carbon. Hence, soil carbon sequestration could produce local economic income as well as social and other benefits in Africa.

The Clean Development Mechanism (CDM) established in the 1997 Kyoto Protocol is designed to give developed countries with high domestic abatement cost access to low-cost greenhouse gas abatement projects in developing countries, and to benefit developing countries selling projects to investors in developed countries. It is presently unclear whether the CDM will provide credit for sink enhancement and permit broader sink activities. Unfortunately, few cost estimates of soil carbon sequestration strategies presently exist. While these costs are uncertain and all input costs have not been estimated, manure-based projects in small-holdings in Kenya could increase maize yield significantly and sequester one ton of soil carbon for a net cost of −US$806. Clearly, such projects would be very attractive economically.

There is presently an urgent need to launch useful long-term (>10 years) field experiments and demonstration projects in Africa. Existing data are not readily comparable, it is uncertain how large amounts of carbon could be sequestered, findings are site-specific, and it is unclear how well the sites represent wider areas. To develop CDM projects, it is important that experimental trials generate reliable and comparable data. Finally, it will be important to estimate local environmental effects and economic benefits, costs, and net costs of soil carbon sequestration projects.

*Key words*: Africa; agriculture; CDM; Kyoto protocol; local economic benefits; sequestration; soil; soil carbon sequestration.

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# 1 Introduction

This article is primarily concerned with soil carbon, a significant part of the total carbon stock in Africa. It examines soil carbon sequestration as a climate policy instrument and explores the opportunities for developing pilot projects for soil carbon sequestration in Africa, especially in the context of the Clean Development Mechanism (CDM).[1]

It is especially relevant to focus on sink management in those world regions that emit small amounts of energy-based greenhouse gas (GHG) emissions.[2] While Africa contributed around only 3 percent of the total global emissions of carbon dioxide ($CO_2$) from fossil fuel burning and cement production in 1995, it could participate in the management of the global carbon cycle through soil carbon sequestration (World Resources Institute 1998, p. 344). Land use systems and agricultural practices increasing the soil carbon stock could produce carbon offsets, and international investments in soil carbon offsets may be possible under the CDM in the future.

Improvements in agricultural techniques and land use practices could lead to higher agricultural productivity and accumulate soil carbon in Africa. Soil carbon sequestration, which essentially is a side-benefit of improved management of agricultural and other land use systems, could produce local economic, social and other benefits in Africa. Sequestration of carbon in soils could become part of a more global comprehensive win–win strategy to manage climate change.

The first section describes briefly the Kyoto Protocol and the CDM. Section two presents an overview of soil carbon sequestration and summarizes findings from Africa. The third section then discusses various management options for soil carbon sequestration in Africa, prevention of conversion of land to agriculture, and restoration of degraded lands. Costs, benefits and net costs of soil carbon sequestration are discussed in the fourth section. The fifth section then briefly discusses some significant opportunities and challenges with respect to the development of soil carbon sequestration projects in Africa. The article ends with conclusions.

[1] Prevention of soil erosion could protect carbon in soils and the savannas could become a carbon sink if savanna burning in Africa was reduced (Gachene at al. 1997; Scholes 1995; Scholes and Hall 1996, pp. 85-86).
[2] Both agriculture and forests can contribute to a reduction in fossil fuel consumption by displacing energy-intensive products (e.g. replacing concrete or steel products with wood products) and increasing the use of energy crops and biofuels. An additional option which, however, has less potential, is to reduce fossil fuel consumption in agriculture and forestry.

# 2 The Clean Development Mechanism

The ultimate objective of the 1992 United Nations Framework Convention on Climate Change (FCCC) is to achieve ‘stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system’ (U.N. FCCC, 1992, art. 2). A Protocol to be attached to the FCCC establishes commitments for all the developed countries and former centrally planned economies to reduce their GHG emissions by the year 2010 with a total of about 5% compared to the 1990 level of emissions. The Protocol, which was negotiated in December 1997 in Kyoto, Japan, does not establish commitments on the part of the developing countries to mitigate GHG emissions. It has yet to be ratified by a sufficient number of countries before it can enter into force.

The Kyoto Protocol establishes the Clean Development Mechanism (CDM), an embryonic institutional framework for direct foreign investments in GHG mitigation projects in developing countries. The objective of the CDM is ‘to assist [developing countries] in achieving sustainable development and in contributing to the ultimate objective of the Convention, and to assist [developed countries and former centrally planned economies] in achieving compliance with their quantified emission limitation and reduction commitments’ (FCCC/CP/1997/7/Add.1, 18 March 1998, art. 12). More specifically, the CDM is designed to give developed countries with high domestic abatement costs access to low-cost mitigation projects in developing countries, and to benefit developing countries supplying projects to investors in developed countries. Developed countries are able to count emission reductions achieved overseas in developing countries against their national climate commitments. The CDM will, in principle, result in an increase in the overall global cost-effectiveness of reducing GHGs. It offers a significant opportunity for increasing financial resource flows from the developed to the developing countries.

The Kyoto Protocol explicitly mentions emissions from sources and removals by sinks as a direct consequence of human intervention affecting land use change and forest related activities – deforestation, reforestation and afforestation – undertaken since 1990. The Kyoto Protocol also identifies agricultural land as a possible carbon source, and agricultural land should be included in the emission inventories that are prepared by the Parties to the FCCC (art. 3.4). However, the Kyoto Protocol does not include provisions for national crediting for carbon sequestration in agricultural soils. Thus, it is presently unclear whether the CDM will provide credit for sink enhancement and permit broader sink activities.

Moreover it is unclear how carbon sink offsets are to be determined. The Kyoto Protocol states that ‘the Parties to this Protocol shall, at its first session or as soon as practicable thereafter, decide upon modalities, rules and guidelines as to how, and which, additional human-induced activities related to changes in greenhouse gas emissions by sources and removals by sinks in the agricultural soils and the land use change’ shall be taken into account (art. 3.4.). The issue was not resolved by the Fourth Conference of the Parties to the FCCC which met in Buenos Aires in the fall of 1998, but might be resolved when the Sixth Conference of the Parties meet in year 2000. There is therefore a possibility that agricultural soils could be included as a terrestrial carbon sink together with forests. At present, there is a growing pressure to include soil conservation in the project portfolio recognized and regulated under the Kyoto Protocol (*New Scientist* 1998, p. 17).

More than 260 million people, or about 30 percent of the total population in sub-Saharan Africa, could be without adequate food by the year 2010 (FAO 1996, p. 271). The agriculture sector dominates the economies of most sub-Saharan countries, contributing about one-third of the region's GDP, accounting for forty percent of the export, and employing about two-thirds of the economically active population (FAO 1996; Hernes et al. 1995). For obvious reasons, increasing the productivity and sustainability of agriculture is a key regional priority, whereas managing global warming is not! Despite this, soil carbon sequestration projects increasing agricultural productivity and bringing economic benefits would present countries in this region with a significant economic incentive. For their part investors and the international community might find soil carbon projects attractive because their positive impact on agricultural productivity gives sub-Saharan host countries a considerable incentive for efficient and sustainable implementation of sequestration projects over time. By contrast, forest carbon sequestration projects with modest local economic benefits are likely to be mis-implemented if host countries would benefit insufficiently.

Moreover, as soil carbon projects could produce local benefits and income in many cases, it seems unlikely that 'carbon farming' projects and systems will be carried out in Africa. The term carbon farming refers to foreign investments in soil sequestration whose major or sole benefit is sequestration of carbon. Thus, carbon farming projects benefit the investor and/or the international community, but they do not bring significant local and/or national benefits. Carbon farming projects therefore would not contribute to the CDM's aim to assist developing countries in achieving sustainable development.

## 2.1 The CDM and Africa

In 1995, a pilot phase for so-called activities implemented jointly (AIJ) was initiated by the Parties to the FCCC. The objective of this pilot phase is to gain practical experience through experimentation with development, negotiation, implementation, and the monitoring and verification of bilateral GHG mitigation and sequestration projects. Investors cannot claim credit from their investment in AIJ projects in the pilot phase. Although CDM is a multilateral mechanism, AIJ experiences will shed light on the way in which CDM could function when it becomes operational.

By June 1999, one hundred and fourteen AIJ projects had been accepted, approved or endorsed by the national parties involved (UNFCCC 1999). But just one of these projects is being carried out in Africa, that in Burkina Faso (World Bank 1999). The reasons for the almost complete absence of AIJ-projects in Africa include low emissions reduction potential, deficient institutional capacity and a weak private sector (UNEP 1998; Sokona, Humphreys and Thomas 1998).

African countries have at regional workshops and in the meetings of the Parties to the FCCC after Kyoto expressed considerable interest in participating in the CDM. Infrastructure, energy and transportation projects have been given highest priority, although agricultural and forestry projects also have been suggested as possible CDM candidate projects (UNEP 1998, p. 8).

# 3 Soil carbon sequestration: An overview

Carbon is distributed, and is being redistributed, among five major interconnected carbon pools – the oceanic pool, the geological pool (consisting of coal, oil and natural gas), the soil, the terrestrial biomass pool, and the atmospheric pool. The soil carbon argument is based upon the assumption that enlargement of the soil carbon stock reduces the concentration of $CO_2$ in the atmosphere. In other words, soil carbon sequestration will redistribute carbon from the atmospheric pool to the soil.

Historically, neither developed nor developing countries have managed soils in order to reduce GHGs emissions or to sequester or store carbon. While policy-makers have yet to recognize the potential of this sequestration option, international expert groups and American, Canadian, and European experts and scientists are increasingly recommending that soil carbon sequestration plays an important role in managing global climate change (e.g. Drinkwater, Wagoner and Sarrantonio 1998; Lal, Kimble, Follett and Cole 1998; for Canada, see, among others, Dumanski, Desjardins, Tarnocai, Monreal, Gregorich, Kirkwoord, and Campbell 1998, and Soil and Water Conservation Society 1998; for Europe, see, among others, Smith, Powlson, Glendining and Smith 1997; Smith, Powlson, Glendining and Smith 1998; see also IGBP Terrestrial Carbon Working Group 1998). By reducing the rate of $CO_2$ accumulation in the atmosphere, this option would buy valuable time to reduce fossil fuel emissions. However, terrestrial carbon sinks are not permanent offsets to fossil fuel emissions (IGBP Terrestrial Carbon Working Group 1998).

Generally, the conversion of native, undisturbed or virgin land to agricultural systems results in a degradation of the soil organic matter (SOM), defined as the sum of all organic substances (dead plants and animals) in the soil, leading to a release of soil carbon to the atmosphere (reports of relative stability of soil carbon following land conversion in Africa do exist however; see Woomer, Palm, Qureshi, and Kotto-Same 1997, pp. 159-160). On average, a new equilibrium or steady-state is established at a lower level after 20-50 years (German Advisory Council on Global Change 1998, p. 24). But exceptions to this general trend do exist. For instance, in the case of forest conversion to well-managed pastures, it might be possible not only to preserve but even exceed the soil carbon level in native forests (Cerri, Volkoff, Andreaux 1991; Lugo, Sanchez, and Brown 1986).

Agricultural techniques have a significant influence on the amount of carbon stored in soil over time. Changes in agricultural practices and inputs – notably changes in crop varieties, application of fertilizer and manure, rotation and tillage practices – influence how much and at which rate carbon is stored in, or released from, soils.

Three general management strategies for preserving and increasing the soil organic matter content in the soil exist: maintain currently existing levels of SOM; restore or rebuild depleted SOM levels; and enlarge and maintain SOM above the natural carrying capacity or steady state (Johnson 1995, pp. 351-363; Kern and Johnson 1993). The natural carrying capacity is the maximum soil organic matter level that can be maintained under a given set of soil, environmental and climate conditions. The three main management strategies are briefly described below.

(i) Anthropogenic use of soils commonly lead to a loss of carbon in the soil. Historically, a significant amount of carbon that was stored in soils and forests has been released as $CO_2$ into the atmosphere. The purpose of the first strategy is to prevent further loss of soil organic matter by introducing soil management practices that preserve and protect soil organic carbon.

(ii) While many land use and management practices have led to a depletion of soil carbon, carbon can be re-accumulated in soils. In some cases it will be necessary to adopt intensive management practices (e.g. repeated fertilizer additions). In other cases minor management changes may be sufficient (e.g. giving up marginal farmland to native vegetation). The objective of the second strategy is to restore the soil organic matter to its pre-management soil organic matter carrying capacity level. But, as discussed in Section 5, in many cases it will only be possible to re-accumulate some but not all of the carbon lost.

(iii) The third strategy aims at increasing the soil organic matter level of soils above their pre-management level. One way to raise the soil organic matter carrying capacity could be through improving soil fertility. But to a significant degree this strategy will rely on factors that cannot be manipulated though human intervention (e.g. climate).

To summarize, emissions from soils could be reduced in some cases, but not completely eliminated. In other cases emissions could be eliminated and soils would become neutral with respect to emissions. And, instead of being a source of carbon releases into the atmosphere, some soils could be converted to sinks absorbing carbon. Importantly, deforestation rates might be lowered because increased agricultural productivity could reduce the demand for new agricultural land. Preserving forest carbon could therefore be a significant side effect of carbon sequestration in soils, in particular in developing countries.

## 3.1 Findings from temperate zone soils

Results from long-term experimental fields in the United States indicate that through agricultural management it is possible to sequester a significant amount of carbon in cultivated land (Buyanovsky and Wagner 1998). Over a period of one hundred years, a direct relationship between the amounts of carbon returned to the soil and soil organic carbon content was observed in these US experiments. Crop residues, manure, and in some cases both, supplied the new annual carbon entering the soil. In addition, management – specifically whether regular tillage was practiced or not – was an important factor for carbon sequestration. Everything else equal, over a period of one hundred years the 100 cm soil layer of no-till plots stored 15-20 tons of carbon per hectare more than plots under regular tillage (Buyanovsky and Wagner 1998).

As stated above, the conversion of native land results in a loss of soil carbon, but it is possible under certain circumstances to rebuild and maintain the carbon soil content to a level close to that of undisturbed land. A 3-year rotation (corn, wheat and clover) with manure and nitrogen, which lost more than 30% of its organic carbon present in its upper 20 cm over a 60-year period, later managed to store almost 135 tons of carbon per hectare in the 1 meter soil layer, a level comparable to that of undisturbed land.[3] Over a period of 26 years, the soil accumulated

[3] Some studies have found that the more active or dynamic part of the carbon in soil is found in the upper 20 cm of the soil profile, while the carbon below that level is considered inactive or stable, with a mean residence

at the annual rate of 1.5 ton of carbon per hectare. In another case, over a 15-year period, continuous corn receiving mineral fertilizers accumulated carbon at a rate about 0.5 ton per hectare per year in the upper 20 cm layer. Over 25 years, 11.1 tons of carbon per hectare were accumulated. This represents a total increase in carbon stored of about 42% (Table 1).

**Table 1: Changes in carbon content in upper 20 cm layer of Sanborn Field soils under different managements, 1963-1988.**

| Crop, treatment | Carbon, ton per hectare | | |
|---|---|---|---|
| | 1963 | 1988 | Change |
| Continuous wheat | | | |
| manure | 32.6 | 42.7 | +10.1 |
| miner. fert. | 27.2 | 36.0 | +8.8 |
| none | 25.4 | 24.4 | -1.0 |
| Continuous corn | | | |
| manure | 32.3 | 37.7 | +5.4 |
| miner. fert., no till | 26.7 | 37.9 | +11.1 |
| miner. fert., convent. till | 24.9 | 32.5 | +7.6 |
| none | 21.9 | 18.2 | -3.7 |
| Corn/Wheat/Clover | | | |
| miner. fert. | 27.8 | 35.9 | +8.1 |
| manure + N | 30.6 | 47.0 | +16.4 |

*Source*: Buyanovsky and Wagner 1998, p. 137.

Numerous other examples of the potential for soil sequestration could be cited. For example, experiments with spring barley showed that addition of farmyard manure led to significant sequestration (Johnson 1995, p. 359). Test plots that received farmyard manure showed an increase in soil carbon from about 30 tons to about 85 tons of carbon per hectare in the 0-23 cm layer. Annually about 0.5 ton of carbon per hectare was sequestered in the soil. Measurements made 100 years after the experiments showed that the soil that had received farmyard manure still contained higher levels of carbon compared to soils that had not received farm yard manure.

## 3.2 Findings from Africa

Compared to developed countries, opportunities for soil carbon sequestration in developing countries are less known, and the technical potential for soil carbon sequestration in Africa and other developing regions is more uncertain. Despite this, studies from Africa are generally in agreement with those from developed countries. Degraded lands and desertification in Africa offer additional opportunities for carbon sequestration. We now turn to a number of findings from Africa.

time of more than 1000 years. But while depths of 0-20 cm, 0-30 and 0-100 cm are used for the sake of comparison, this practice does not seem to be scientifically justified. For a discussion, see Batjes and Sombroek 1997, pp. 163-164. See also Greenland 1995, p. 10.

## 3.3 Semiarid savannas and dry forests

In West Africa, overgrazing and demand for fuel wood has led to serious land degradation in savannas, resulting in low biomass and soil carbon levels (Tiessen, Feller, Sampaio, and Garin 1998). Short fallow periods contribute insignificantly to maintaining soil organic matter and, because crop residues are either removed or burned, 50-70% of the land receives minimal carbon returns to the soils and thus contains very low carbon levels.

Arable agriculture and animal husbandry is practiced in semiarid West Africa between 500-1100 mm annual precipitation on an area of about 3,000,000 $km^2$. Because of high rural population density as well as high animal density, some areas, such as central-western Senegal, are increasingly overexploited and overstocked. In this region, where mean annual rainfall ranges from 500-650 mm, three types of land use management zones with distinct organic matter budgets and cycles can be distinguished.

The first type is comprised of range-land consisting of degraded brushy savanna. Because of degradation of the savanna, the soil stores only about 7.5-9.9 tons of carbon per hectare in the upper 20-cm layer.[4] The non-degraded savanna is characterized by higher plant productivity and organic matter returns which result in higher soil carbon levels of about 7.5-18.0 tons of carbon per hectare (2.5-6.0 g of carbon per kg), or a 20-30% difference between degraded and non-degraded savanna (Tiessen, Feller, Sampaio, and Garin 1998, p. 113).

The second type of land use management is characterized by land that is continuously cultivated without application of animal manure and left to fallow for about one in five years. It also stores small amounts of carbon. In this system, residue levels are low because above-ground residues are used as fuel, construction, fodder or are burnt prior to the next cropping. The soil carbon levels range from 4.5 to 13.5 tons of carbon per hectare (1.5-4.5 g of carbon per kg).

In the third system, where continuously cultivated land receives animal manure, soil carbon levels are raised approximately 40% on individual sites, corresponding to levels ranging from 6.0 to 14.2 tons of carbon per hectare (2.0-4.7 g of carbon per kg).

As a result of cultivation, soil carbon levels of degraded savanna decreases by 40% in 3-5 years for sandy, and 5-10 years for clayey sand soils in the region as such. But application of animal manure and crop rotation improve soil carbon levels and productivity. Short periods of fallow have little effect on soil quality but, if extended and managed adequately, may help to maintain quality of soil and sequester carbon. With respect to degraded savannas, fire prevention and animal exclusion could increase productivity as well as sequester around additional 25% carbon in soils. While unfertilized cropland is potentially able to store more carbon by fertilizer application and better management, this option is presently constrained by the limited economic capacity in the region.

Generally, only modest amounts of carbon are stored in the soil in the semi-arid tropics, including in the natural ecosystem. Although increasing soil fertility, the use of crop residues as surface mulches and fertilizer may not result in significant storage of carbon in the soil of the

[4] The author has converted the carbon content of the soil, in this case 2.5-3.3 g C $kg^{-1}$, into t C $ha^{-1}$, assuming a bulk density of 1.5. Christian Feller, personal communication. The bulk densities of these soils ranged from 1.1 to 1.6. Alain Albrecht, personal communication.

semiarid tropics of West Africa (Geiger, Manu and Bationo 1992). The opportunities for soil carbon storage seem therefore limited.

## 3.4 Cultivation of woody savannas

In general, approximately 50% of the soil organic carbon in tropical woodlands, grassland or savanna soils converted to croplands is lost in 20 years (Scholes and Hall 1996, p. 92). Losses are generally highest in the tillage horizon or the topsoil (0-20 cm).

Converting woodland and broadleaf savannas to agriculture have resulted in loss of soil carbon in Southern Africa (Woomer 1993). Results from research plots in Zimbabwe (Marondera) show a decline in soil carbon of about 9% after 8 years of continuous maize cultivation, and comparison with similar soils cultivated with maize over long time periods indicates a soil carbon loss of as much as 18.6 ton of carbon per hectare, or a 67% loss. A Guinean savanna experienced a relatively smaller loss – 5.2 tons of carbon, or 22% – as a result of maize-based cultivation.

A number of reports of soil carbon loss due to continuous cultivation in Africa are presented in Table 2. They are not readily comparable because soil depths, measurement periods and regions differ. Longer-term climatic patterns (e.g. the effects of a prolonged drought) may also influence results. Nevertheless, these reports confirm that cultivation commonly results in carbon loss from soils.

**Table 2: Reports of soil carbon loss due to cultivation in sub-Saharan Africa.**

| Soil C loss t/ha/yr | Conditions | Soil depth cm | Period years |
|---|---|---|---|
| 10 | Cultivation following land conversion in Western Kenya | 0-37.5 | 2 |
| 8 | Slash-and-burn conversion in coastal Mozambique | 0-20 | 4 |
| 6 | Comparison of forest and cultivated Nitisol in the Kenyan Central Highlands | 0-15 | 8 |
| 2.7 | Moimbo woodland in Zimbabwe converted to maize cultivation in a sandy Alfisol | 0-50 | 6 |
| 2.4 | Cultivation following land conversion in Western Kenya | 0-37.5 | 30 |
| 2.2 | Following forest clearing in Southern Cameroon by slash-and-burn | 0-40 | 4 |
| 0.9 | Continuous cultivation in Western Kenya | 0-37.5 | 18-30 |

*Sources*: P. L. Woomer et al. 1997, p. 159.

As previously mentioned, however, under some circumstances it is possible to restore the soil carbon content to a level near that of undisturbed forest. For instance, according to experiments conducted in Nigeria, the first seven years after forest clearing the soil organic carbon content was reduced from approximately 25.5 to 13.5 tons of carbon per hectare (from 17 g to 9 g per kg) in the upper 15 cm layer, but bush fallow after 12-13 years raised the carbon content to a level similar to the pre-clearing level (Juo, Franzluebbers, Dabiri and Ikhile 1995).[5] Guinea grass and leucaena fallows also exhibited a 7-year decrease in soil carbon followed by a reconstitution of carbon to around the initial level; pigeon pea fallow, however, was unable to sequester an equal amount of carbon, most likely due to lower biomass production and a lower carbon-nitrogen ratio of pigeon pea residues. Chemical properties of the soil under pigeon pea

[5] Calculated by the author.

fallow also deteriorated compared to bush fallow and Guinea grass and leucaena fallows. Such experiments shed light on the question whether planted fallow, especially by applying nitrogen fixating legumes or grasses producing high amounts of biomass, makes it possible to return to cropping sooner compared to natural bush fallow. More fundamentally, they indicate that fallow is important in order to preserve soil productivity and sequester carbon in the forest/savanna areas of West Africa.

Experiments with three different cropping systems – continuous maize with stover returned as surface mulch or removed from the field, and maize/cassava intercrop with maize stover returned – were also conducted in Nigeria. These generally showed that soil organic carbon dropped during the first eight years after forest clearing and, rather than increasing to the original level, then remained 35% below the level maintained by bush fallow. Despite application of N, P, K and Zn fertilizers, the maize grain yields of the first season decreased from about 6 tons per hectare to 1.5 tons per hectare during the first 9 years following forest clearing. It subsequently stabilized around 2.5 tons per hectare.

Table 3 shows results from experiments with continuous cropping with and without fertilizers and manure addition in Kenya. The initial carbon stocks ranged from 30.2 to 44.1 tons of carbon per hectare in the 0-20 cm top layer. Over a 4-7 year period, the average annual loss due to cultivation was 0.69 tons of carbon per hectare. Fertilizer addition resulted in most cases in a small carbon increase, although some soils showed net losses, especially where phosphorous was added. Addition of farmyard manure consistently resulted in an increase in soil organic carbon, although the added amount (5-7.5 t/ha/yr) was unable to balance the total losses in the case of Acrisols and Luvisols.

**Table 3: Carbon stocks in agricultural soils of Kenya, annual carbon losses due to cultivation, and changes in annual C fluxes due to chemical fertilization and livestock manure addition.**

| FAO soil order | Total soil C | Soil C flux (tC/ha/yr) | | C flux from applying… tC/ha/y N | P | N&P | Manure |
|---|---|---|---|---|---|---|---|
| Acrisols | 44.1 | -1.24 | | 0.11 | 0.01 | 0.58 | 0.89 |
| Ferralsols | 38.0 | 0.21 | | 0.46 | 0 | -0.09 | -- |
| Luvisols | 30.2 | -0.90 | | -0.11 | -0.55 | -0.32 | 0.45 |
| Nitisols | 43.1 | -0.49 | | 0 | -0.05 | 0.10 | 0.92 |
| All soils | 39.5 | -0.69 | Total | 0.07 | -0.14 | 0.11 | 0.80 |

*Source*: Paul L. Woomer et al. 1997, p. 161.

# 4 Management options for soil carbon sequestration in Africa

A considerable number of specific agricultural management and land use options are available for carbon sequestration in tropical and subtropical soils. The list below contains a number of land use and management practices and technologies that are frequently suggested in the literature (Batjes and Sombroek 1997, p. 168):

(1) conservation tillage (no-till/minimum-till) in combination with planting of cover crops, green manure and hedgerows

(2) organic residue management

(3) mulch farming, particularly in dry areas

(4) water management, including *in-situ* water conservation in the root-zone, irrigation, and drainage to avoid potential risk of salinization and water-logging

(5) soil fertility management, including use of chemical fertilizers and organic wastes, rhizobium inoculation, liming and acidity management in order to take full advantage of the $CO_2$-fertilization effect

(6) introduction of agroecologically and physiologically adapted crop/plant species, including agroforestry

(7) adapting crop rotations and cropping/farming systems, with avoidance of bare fallow

(8) controlling of grazing to sustainable levels

(9) stabilizing slopes and terraces.

The usefulness and effectiveness of these options will vary according to local ecological and climate conditions. With respect to option (1), one South African study found no consistent trends in the effect of reduced tillage or no-till practices on soil organic carbon (van der Watt 1987). However, another study found that conservation tillage reduced emissions of carbon from soils, especially where wheat was rotated with an annual legume pasture (Agenbag and Maree 1989). In the humid zone, it will be important to take into account various soil types (Paustian, Cole, Sauerbeck, and Sampson 1998, p. 147). With regard to option (6), with over 2000 mm annual rainfall, an increase of 25-70 tons of carbon per hectare during 5-10 years after establishing pastures of deep-rooted grasses in Columbia has been reported (Fisher et al. 1994).

These technologies and land use practices resulting in the accumulation of soil carbon vary significantly with respect to external input. In general, options (1), (2) (to the extent that organic residue is available), (3), (7), and (8) are achievable with existing resources. They are not dependent upon availability of additional resources but require a change in the way in which existing resources are applied. By contrast, options (4), (5), and (9) are dependent upon additional resource input. Options (5) and (6) either might not be available today, or have yet to applied on a broad scale. Hence, some of these options are possible with existing socio-economic resources, while others only will be realized through additional resource input, for example foreign investments in soil carbon sequestration under the CDM.

## 4.1 Land use conversions in Africa

A second group of options is concerned with reducing or preventing the conversion of land to agriculture in tropical Africa. One useful way to organize these mitigation options is by ecological zone – the arid-semiarid, sub-humid, and humid zones (Table 4). The three zones are broadly defined according to climate and soil fertility characteristics.

Soil and biomass carbon stocks are quite small in the semiarid zone and there is in general little opportunity to mitigate emissions through changing land use. Agricultural lands are mostly concentrated in the sub-humid zone. By improving management methods and increasing productivity in ways such as outlined above, it should be possible to limit the expansion of agriculture. Increased productivity and sustainability could, moreover, reduce the demand for clearing forests (deforestation) and savannas to meet local agricultural and economic needs. A major potential for $CO_2$ mitigation from converting to agricultural land exists in the humid zone and in tropical wetlands.

**Table 4: Main land use related mitigation options by ecological zone in Africa.**

| Rainfall zone | Typical soil fertility | Critical issues in land use | Carbon mitigation options. |
|---|---|---|---|
| **Arid-semiarid** <1200 mm | Low-medium | Desertification | Prevent desertification. |
| **Sub-humid** 1200–2500 mm | Low-medium | Most land currently used for agriculture | Improve pastures with introduction of deep-rooted grasses. |
| **Humid** >2500 mm | Poor, strongly leached soils | Deforestation, Intensification of agriculture | Large above-ground carbon stocks can be maintained with reduced deforestation, improved forest management. |
| Wetlands | Organic soils | Conversion for rice and upland crops | Large below-ground C stocks can be maintained if native wetlands are left intact. |

*Source*: Paustian, Cole, Sauerbeck, and Sampson 1998, p. 139.

In summary, degraded lands offer a large potential carbon sink. Large portions of agricultural lands in Africa are degraded or desertified (Table 5). Restoration of degraded soils through improved farming systems could lead to a considerable increase in soil carbon. A number of techniques and measures have been suggested in order to restore agricultural lands. Prevention of deforestation, afforestation and reduced burning of savannas would reduce the release of carbon into the atmosphere. Grasslands and pastures can be improved by controlling grazing, using improved pasture species, and using chemicals and soil amendments (Lal, Kimble, and Stewart 1995, p. 5).

**Table 5. Areas in millions of hectares of agricultural land, permanent pasture, and forest and woodland of Africa, and the portion of these areas affected by human-induced soil degradation.**

| | Agricultural land | | | Permanent pasture | | | Forest and woodland | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total | Degraded | % | Total | Degraded | % | Total | Degraded | % |
| Africa | 187 | 121 | 65 | 793 | 243 | 31 | 683 | 130 | 19 |

*Source*: Greenland 1995, p.16.

Although these estimates are useful on the regional and global levels, they are less so in assessing local and project level opportunities for soil carbon sequestration. Thus it is necessary to look more carefully at the amount of land that is socio-economically rather than technically available.

# 5 Costs, benefits, and net costs of soil carbon sequestration

It is important to carefully estimate the costs and benefits of various soil carbon sequestration strategies. The direct and indirect costs should both be included in the sequestration assessment, as pointed out in one study: ‘The carbon, or energy, costs of fertilizer production, transportation, and application must also be included in the carbon sequestration equation’ (Johnson 1995**,** p. 359). All project development, input, labor, monitoring, and verification costs must be taken into account and compared. Local economic, environmental and social benefits of soil carbon sequestration should also be included in order to estimate the net cost. Moreover, opportunity costs – that is, the foregone benefits of land use alternatives – should be estimated.

Unfortunately, few cost estimates of soil carbon sequestration strategies exist for Africa and other world regions, and surprisingly little is known about their local economic benefits and income (for an overview over relevant economic models and crop models, see Halsnæs, Callaway, and Meyer 1999, pp. 121-137 and pp. 202-208). Until the necessary data become available and are correctly analyzed, it will not be possible to select attractive land use and management strategies and technologies for carbon sequestration in Africa.

## 5.1 Carbon sequestration efficiency and local economic returns

Dependent upon soil and environmental conditions as well as resource availability, different land use changes and agricultural strategies could accumulate soil carbon. The most attractive options for an investor are those that sequester the most carbon per resource spent or sequester the most carbon at the least cost. The most attractive strategies for the farmer are those which provide the greatest increase in agricultural yield, or bring other economic or social benefits.

A pioneering study by Woomer and co-workers examined six alternative soil carbon sequestration strategies in small-holdings in Kenya. They examined the carbon sequestration efficiency – defined as the change in soil organic carbon due to carbon inputs expressed as a percentage of the carbon inputs – the input cost, and effects on agricultural yield (Woomer et al. 1997, p. 162). The six strategies mixed application of maize stover, manure and fertilizer are given in Table 6 along with carbon efficiency and economic return.

**Table 6: C sequestration strategies, C sequestration efficiency, and economic return.**

| C sequestration strategy | Carbon seq. efficiency | *Rank* | Economic return | *Rank* |
|---|---|---|---|---|
| A. Fertilizer and stover | 1.4 | 6 | 1.3 | 5 |
| B. Stover | 5.4 | 3 | -1.3 | 6 |
| C. Manure | 5.5 | 2 | 4.1 | 1 |
| D. Fertilizer and manure | 6.9 | 1 | 1.6 | 3 |
| E. Stover and manure | 3.6 | 5 | 1.8 | 2 |
| F. Fertilizer, stover and manure | 3.8 | 4 | 1.4 | 4 |

The carbon efficiency of the options differed greatly. Positive economic returns varied from 1.3 to 4.1. The only exception was stover management alone with an economic return of -1.3 – a net loss – although it had a high carbon sequestration efficiency.[6] This may be illustrated diagrammatically as in Figure 1.

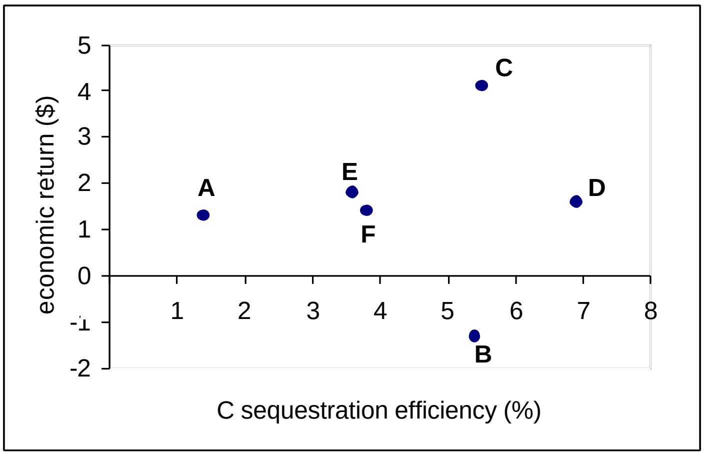


**Figure 1: Economic return and C sequestration efficiency of six land use management strategies, East African Highlands.** *Source*: Based on Paul L. Woomer et al., 1997.

Clearly, option B would be unattractive economically to farmers. Apart from the economic rent from carbon offset sales, option B would bring no farmer benefits, only farmer costs. It could be seen as an example of a carbon farming project (carbon farming projects were discussed in Section 1). Nevertheless, option B is more carbon efficient than options F, E, and A. Option D is the most attractive choice from the standpoint of carbon sequestration, but it results in less economic return than options C and E.

If assuming, for a moment, that input costs are identical, and that investors are indifferent about local economic benefits and costs of various carbon sequestration options, then investors would rank the six options in the following way: D>C>B>F>E>A. Similarly, assuming that farmers are indifferent about the impact on soil carbon stocks, they would rank the options in the following way: C>E>D>F>A>B.

It is not possible to maximize both carbon efficiency and economic return in this example. Instead, a trade-off between these two goals must be made. Notice that choosing the second-best option with respect to economic return, option E, would mean a sizable relative economic loss compared to the second-best sequestration choice, option C. Nevertheless, both farmers

[6] The reason why stover management had a negative effect on yield is not apparent from the study.

and investors would rank options C and D among their three most attractive options. It should therefore be expected that investors and farmers primarily would focus on options C and D in exploring project possibilities for carbon sequestration.

While Woomer et al. examined six strategies for soil carbon sequestration, alternative combinations or mixes of the carbon inputs from maize stover, manure and fertilizer might impact positively on soil carbon stocks. In addition, in order to either sequester more carbon or increase economic returns – or both – they might be usefully combined with some of the land uses and management practices outlined in the previous section.

Generally, four groups of alternative strategies exist (Figure 2). Some options would benefit farmers but not investors (Box 1), while others would benefit investors but not farmers (Box 4). A third group of options would be universally unattractive as neither farmers nor investors would benefit (Box 3), but a fourth group would benefit both farmers and investors (Box 2). Box 2 options are technically known as win-win options. Both groups win – neither lose – should these options be available and selected.

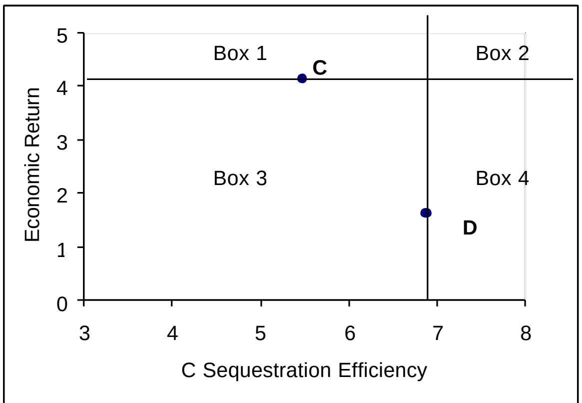


**Figure 2: Four groups of sequestration projects compared with respect to their carbon sequestration efficiency and economic return**.

It should be stressed, however, that the cost of carbon inputs, labor and other inputs, as well as net cost, will vary significantly and hence influence the attractiveness of individual sequestration options. Most studies ignore the costs and benefits of soil carbon sequestration. One exception is the above-mentioned study of the East African Highlands by Woomer and colleagues. They reported that it would cost $153 when maize stover was used in sequestering one ton of carbon, but that maize yields would be reduced by a value of $200 (Woomer et al. 1997, p. 162 and p. 169). In this case, they concluded, the cost of sequestration of one ton of soil carbon would be $353. Alternatively, they concluded that when livestock manure was used, the cost of sequestration of one ton of carbon would be identical to the input cost of $260. They noted that livestock manure application would increase yields by a value of $1066.

But this conclusion confuses input costs and benefits. Furthermore, it ignores *net costs*. First and foremost, it should be stressed that two very different commodities were produced; an agricultural commodity, in this case maize, and soil carbon offset(s). The latter could be saved or sold in the offset market if such a market existed. As already mentioned, the input cost of the maize stover-based sequestration project was $153 and a yield loss worth $200 resulted. Hence, the net cost to the farmer of this carbon sequestration project was $353. Similarly, input cost of application of livestock manure was $260, but a yield increase worth $1066 was achieved. Hence, the net cost to the farmer of the manure-based carbon sequestration strategy was –US$806 (Table 7). The agricultural productivity gains from the second strategy entirely covered the input costs, even though these were higher for manure than for maize stover. Soil carbon sequestration was not simply cost-neutral: it produced a net economic benefit of $806.

**Table 7: Input cost, effect on yields and net cost of carbon sequestration in soils of smallholder settings of the East African Highlands.**

| Type of carbon input, land use system | Input cost/t C $ | Effect on yields $ | Net cost $ | Comments on cost estimates |
|---|---|---|---|---|
| Stover, smallholder agriculture | 153 | -200 | 353 | Labor costs excluded. |
| Manure, smallholder agriculture | 260 | 1066 | -806 | Labor costs excluded. |
| Smallholder agroforestry | 87 | n.a. | n.a. | No costing of erosion control, tree planting, and fertilizer input. A full-time farmer managing the project, at a cost of $40/hectare, is included in estimate. |

*Source*: Based on Paul L. Woomer et al. 1997. n.a.= not available.

Clearly, the negative net costs justify this sequestration project economically. From an economic point of view, the manure-based sequestration strategy presents an opportunity for economic gain and would therefore be considered as a spontaneous or self-implementing project. It exemplifies a so-called no-regrets project; by definition these projects bring economic benefits irrespective of the occurrence of a future climate change. But lack of investment capital, unawareness of economic opportunities, institutional barriers, property rights and other factors may often prevent the realization of no-regrets options. Institutional reform and capacity-building may therefore be necessary in order to remove barriers preventing the realization of no-regrets options.

Moreover Woomer and colleagues estimated that properly managed agroforestry systems could raise the total sequestered amount from 70-136 tons of carbon per hectare by including above-ground biomass carbon in addition to below-ground carbon. This, they estimate, would mean an input cost of $87 per ton of carbon. Because the agroforestry system’s impact on yield was not estimated, however, it is not possible to calculate the net cost in this case. It was estimated that an amount of 66 tons of carbon could be sequestered over 20 years, i.e. an annual increase of around 3 tons of carbon per hectare.

Unfortunately, it is not possible to compare the net costs of the stover-based and manure-based strategies with the net costs of other forestry and agroforestry strategies because most studies ignore the local costs and benefits. For instance, in their study of carbon sequestration in agroforestry systems, Dixon and co-workers found that the project costs ranged from $1 to $69 per ton of sequestered carbon (Dixon et al. 1994, p. 86). Local benefits were expected to accrue, but quantitative estimates were not made. Local benefits and costs of forestry and agroforestry projects sequestering carbon are seldom quantified but it is assumed that projects provide a stream of economic, social and environmental benefits over time at the local level (e.g. Faeth, Cort and Livernash 1994).

Finally, the input cost or project cost of the agroforestry-based carbon sequestration system suggested by Woomer and co-workers compares unfavorably to the input cost reported by Dixon and co-workers. But again, it is necessary to include local economic, social and environmental benefits in order to estimate the net cost of carbon sequestration projects.

## 5.2 Local benefits from soil carbon and forest carbon sequestration

Developing countries will most likely not consider sequestration projects attractive unless they produce local income or national benefits. As stressed by the United Nations Inter-Governmental Panel on Climate Change (IPCC) and others, farmers and society at large should receive additional benefits – for instance, reduced labor and reduced or more efficient use of production inputs – from soil carbon sequestration projects (Cole et al. 1996, p. 748; Batjes and Sombroek 1997, pp. 169-170). Moreover, as noted earlier, project implementation would be uncertain if a sufficient incentive for the host country does not exist.

It should be expected that developing countries will select those sequestration projects that create the largest local benefits. Which options, then, would benefit African countries the most? Clearly, this is an essential question and comparing soil management, forestry and agroforestry systems for their economic, social and environmental effects will increasingly be necessary.

Local economic interests and the land use management system sequestering the largest amount of carbon will sometimes be at odds (Figure 3). On the one hand, soil carbon sequestration may often create larger local economic benefits than forest carbon sequestration. The high rate at which forests are currently being converted to agriculture in Africa indicates that economic return from agriculture is higher than from forests, at least in a short-term perspective, and that the land is more valuable deforested than forested.[7] On the other hand, a larger amount of carbon can be sequestered in above-ground biomass systems than in soils. Forest carbon will therefore be more favorable from the point of view of carbon sequestration.

[7] According to the most recent estimates, the total change in the above-ground forest carbon pool in Africa throughout the period 1980-1990 due to changes in land cover and land use is estimated to be a decrease of 6.6 billion tons of carbon. Assuming an equal change in carbon pools for the period 1980-1990, this would be equal to an annual decrease of about 660 million tons of carbon during that period. On average, 43% of this decrease was due to deforestation, while 57% was due to biomass reduction caused by other human activities (Gaston, Brown, Lorenzini, and Singh 1998).

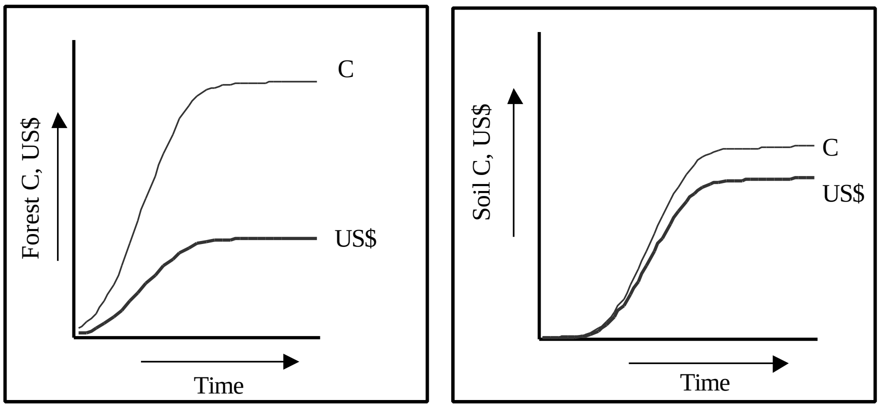


**Figure 3: Comparison of sequestration potential and local economic income from forest carbon and soil carbon sequestration**.

In a number of cases it will not be practically possible to realize the technically available carbon sequestration potential. Thus it would be useful to explore opportunities for combining or packaging soil carbon and forest carbon projects in ways that both sequester a significant amount of carbon and at the same time create sufficient local economic income. Such packages of soil carbon and forest carbon might make carbon sequestration sufficiently attractive both to investors in developed countries and hosts in developing countries.

# 6 Soil carbon sequestration: Opportunities and challenges for Africa

This section briefly discusses the potential for soil carbon sequestration in Africa, measurability and monitoring of soil carbon, permanence of soil carbon stocks, climate change, and environmental side-effects of soil carbon sequestration. The need for detailed assessments of local benefits and costs of sequestration, the importance of capacity-building in sub-Saharan Africa, the additionality concept, and profit sharing and leakage is also underlined. These issues are important in assessing the practical feasibility of soil carbon sequestration projects in Africa.

## 6.1 The potential and time scale for soil carbon sequestration in Africa

It is generally assumed that a certain upper limit exists as to how much carbon can be stored or sequestered in soil. A simple way to estimate the potential for carbon sequestration in soils is to assume that the soil carbon content can be re-established or rebuilt to the original, pre-cultivation level (Paustian, Cole, Sauerbeck, and Sampson 1998, p. 140). But this assumption seems too optimistic and unrealistic. In addition, it focuses attention on the technically available, as opposed to the socio-economically available potential.

Currently, an authoritative assessment of the potential for soil carbon sequestration in Africa does not exist. The IPCC suggests that the recoverable level would amount at most to between one-half and two-thirds of the historic carbon loss (Cole et al. 1996, p. 751). Approximately 25-30% of the carbon originally present in the soil has been lost as a result of cultivation in Africa (Paustian, Cole, Sauerbeck, and Sampson 1998, p. 146; according to the IPCC, about 20-50% of the soil carbon in tropical agricultural systems has been emitted as a result of permanent cultivation, see Cole et al. 1996, p. 751). Thus, from a technical point of view, it seems possible to achieve somewhere between 13-20% of the carbon that has been emitted from soils in Africa. But the practical potential is unknown.

How long, then, would it take to sequester this amount of carbon in Africa? According to the IPCC's estimates, this could be sequestered within 50 to 100 years (Cole 1996, 751).[8] For comparison, a recent study predicts that a significant portion of the potential for carbon sequestration in cropland in the United States and Canada may be realized within the next 20 to 30 years (Soil and Water Conservation Society 1998, p. 7).

## 6.2 Measuring and monitoring soil carbon

The issue of measurability of soil carbon flux relates closely to issues regarding monitoring and verification of carbon offsets. This issue is essential for the functioning, reliability and effectiveness of soil carbon sequestration projects, and project baselines would be established on the basis of soil carbon measurements. As a rule, measurement and monitoring of carbon

[8] The IPCC estimates the total global potential for carbon sequestration in cultivated soils.

sequestration projects should be reliable, cost-effective, technically sound, readily verifiable, independent and objective, and use internationally peer-reviewed methods (MacDicken 1997).

It is possible to produce reliable soil carbon inventories by using currently available measuring methods and techniques. But certain common economic limitations of monitoring should be acknowledged (Winrock International 1997, pp. 18-19). First, projects that fix small amounts of carbon are less likely to be monitored cost-effectively because the costs of measuring these small amounts are almost the same as the costs of monitoring much larger amounts of soil carbon. Second, the size of the project area is also a limiting factor on cost-effective monitoring of carbon. As a rule, because fixed costs constitute a large part of the total monitoring costs, the larger the project area, the lower the unit costs of monitoring. These general economic limitations might be particularly significant in the context of soil carbon. Moreover, in comparison with monitoring of forest carbon, there will be less opportunity for measuring soil carbon remotely, and ground-based information will be necessary for estimating soil carbon stocks and fluxes (for soil carbon sampling methodologies, see Winrock International 1997, pp. 67-74).

Some experts tend to believe that it will be prohibitively expensive to establish a field monitoring program based on on-site measurements that track soil carbon fluxes with sufficient precision to be considered satisfactory under the Kyoto Protocol (Lal, Hassan, Dumanski 1999, p. 58). But few studies have addressed this essential issue. It is technically possible to measure and quantify carbon fluxes in soils, but is it economically feasible? Clearly, well-designed experiments that will shed more light on the feasibility, cost-effectiveness and accuracy of measurements are urgently needed.

## 6.3 Permanence of soil carbon stocks

It is evident that soil carbon re-accumulation schemes would need to be in place over long time-scales and thus raise the issue of whether carbon stocks are permanent or potentially reversible. How could soil carbon stocks be protected against subsequent destructive interference resulting in soil carbon losses?

In this context, it should be realized that below-ground carbon normally is more protected than above-ground carbon during fire and other destructive events. Moreover, forests might be felled at a later point, but it is most unlikely that agricultural soils will be reverted back to forests in Africa. Neither does it seem likely that farmers who use conservation tillage will go back to intensive tillage practices. Evidently, more work is needed on the question of permanence of soil carbon stocks. For instance, certain types of contract might minimize such project failure risks.

## 6.4 Climate change

Because climate change will most likely increase the amount of soil carbon sequestered, due to the fertilization effect of mounting $CO_2$ concentrations in the atmosphere, climate change effects would need to be taken into account. If not, windfall credits would accrue and significant uncertainty about projects' impact on carbon would prevail. Obviously, it is essential to know precisely how much carbon is sequestered by projects and how much is caused by factors outside the projects. The $CO_2$-fertilization effect exemplifies a change in exogenously given project variables or changing boundary conditions.

This type of uncertainty is relatively benign in this case. By comparing the increase in carbon accumulated at project sites with observations from reference plots it would be possible to separate and measure the effectiveness of projects and the $CO_2$-fertilization effect. Physiological, biochemical models could also be used to isolate the $CO_2$-fertilization effect. Other ways in which global warming may effect projects – among other things changing precipitation and moisture patterns, and temperature changes – should also be controlled for (for models and discussion, see Parton, Scurlock, Ojima, Schimel, Hall, and SCOPEGRAM, 1995; King, Post and Wullschleger 1997; Cao and Woodward 1998).

## 6.5 Environmental side-effects

N-fertilizer application, animal manure, crops residues and nitrogen derived from N-fixing legumes could contribute to an increase in nitrous oxide ($N_2O$) emissions (Mosier et al. 1998, pp. 7-38). Over a 100-year time horizon, $N_2O$ is 310 times more potent than $CO_2$ in affecting or 'forcing' the global climate system (Houghton et al. 1996, p. 22). However, available data indicate that the amount of carbon that is sequestrated by using nitrogen-based fertilizers will be many times larger than the $N_2O$ emissions resulting from such fertilizer use (Lal, Hassan, and Dumanski 1999, p. 59; however, see Schlesinger 1999). According to recent IPCC estimates, 2.1 million tons of synthetic nitrogen and 10.5 million tons of manure nitrogen are consumed annually by the agricultural sector in Africa at present (Cole et al. 1996, pp. 761-762). These estimates are uncertain and rely on insufficient data. The consumed amount varies dramatically across African countries.

It is worth stressing that there could be significant environmental benefits from soil carbon sequestration projects. For instance, reduced tillage could increase water-holding capacity of soils which, in turn, would reduce the need for irrigation.

## 6.6 The importance of economic and social analysis

As has been constantly emphasized, there is a need for much more analysis of the costs and benefits of various soil sequestration options in Africa, both at the project level and more aggregate levels. More socioeconomic research is also needed to develop systems which provide the greatest economic and social benefits from soil carbon sequestration. In addition, economic sector models and macro-economic modes could be useful in examining the consequences of increasing agricultural productivity and economy-wide implications.

## 6.7 Capacity-building and institutional strengthening

The institutional infrastructure which is in place in Africa today would be insufficient for participating in a future offset market and attracting significant foreign investments. It would be necessary to assist Africa in developing the institutional capacity that is necessary to fully participate and benefit from the global carbon offsets market, should such a market come into existence. Capacity-building and institutional strengthening, including stimulation of the private sector, would be important in order to prepare Africa for participation in international offsets under the CDM.

## 6.8 Carbon sequestration in soils and additionality

According to the rules in the FCCC and the CDM, only carbon sink management and sink enlargement that is additional to that which would occur in the absence of the project would be qualified for crediting. In other words, to qualify as a CDM project, only investments in carbon sequestration activities over and above the baseline or the reference scenario would be credible. The involved parties must be able to demonstrate that the project would not have been introduced in the absence of the CDM.

As this article illustrates, soil carbon sequestration could nevertheless produce significant local benefits and projects would therefore create significant local economic gain. But, if interpreted narrowly, the additionality requirement would mean exclusion of revenue-generating projects because it is assumed that financially attractive projects spontaneously attract the necessary investment and will be undertaken for reasons unrelated to carbon sequestration (or emission abatement). The existing international rules concerning this issue are based on the assumption that all opportunities for achieving economic gain from activities reducing GHG emissions or maintaining or enlarging carbon sinks are, in principle, exhausted in the reference scenario.

Nevertheless, the IPCC acknowledges the existence of ‘no-regrets’ projects that are beneficial irrespective of the occurrence of climate change, and CDM projects could help overcome project barriers, such as a lack of funding, need for technical expertise, or institutional barriers. It therefore is important to distinguish between those opportunities, including no-regrets options, which exist in the ‘real world’ as compared to those that only exist in an ideal world of perfect markets and complete information. A better approach would distinguish, on a case-to-case basis, between those investments that are expectable given various financial, institutional and other constraints in the reference scenario and win-win projects and no-regrets projects.

## 6.9 Profit sharing and leakage

But important distributional issues might arise with regard to soil carbon sequestration. More generally, it is likely that no-regrets and win-win projects would raise the issue of how investor and host should share the profit generated by projects. The issue of profit sharing from CDM and AIJ projects has so far not been addressed because local income has seldom been taken into account. It seems quite evident, however, that an investor would be interested in accruing at least some of the non-GHG benefits from CDM projects. Intuitively, a host will often prefer to acquire all local profit. However, it might in some cases prefer to share some of the profit, at least in order create a sufficient incentive for the investor.

It should therefore also be emphasized that win-win and no-regrets projects could have a significant impact on the offset market. In the case discussed earlier, farmers would clearly gain even if they do not receive the rent from the sale of carbon offsets. For instance, if the investor received $600 in profit from the manure-based project in addition to a carbon credit free of cost, then farmers would still earn $206. In the extreme case, the farmer still benefits as long as the investor receives less than $806 plus the interest from the carbon offset. Evidently, sequestration and mitigation projects with positive costs will not be as attractive to investors as no-regrets and win-win projects. Hence, depending upon the supply of no-regrets and win-win projects and the demand for offsets, these projects could reduce offset market prices significantly.

Finally, it should be stressed that carbon sequestration in soils might avoid problems of leakage because of their positive local effects. The term leakage refers to the situation where a project unintentionally shifts an undesirable activity from the project site to another site, for instance a forest protection project that prevents deforestation within the project area, and instead increases deforestation outside this area. These projects are not achieving their purpose but are shifting the targeted problem around instead of solving it. However, soil carbon sequestration systems are unlikely to create leakage effects because they will frequently be more desirable than alternative land use systems.

# 7 Conclusions

Improvements in agricultural techniques and land use practices could increase agricultural productivity and at the same time accumulate soil carbon in Africa. Recent studies and reports indicate that a considerable opportunity for soil carbon sequestration exist in Africa (for a more sceptical view, see German Advisory Council on Global Change 1998, p. 28; more generally, see Schlesinger 1999). Many of the soils of the tropics, despite their original low productivity, could be vastly improved by management and science-base inputs. As illustrated by the manure-based strategy examined in Section 4, carbon sequestration could bring global environment benefits as well as significant local economic benefits in Africa.

Soil carbon is currently not included among the GHG sinks that are regulated under the CDM. Nevertheless, the attractiveness of this option is that it could combine the goal of sustainable development in developing countries with carbon sequestration. Additionally, increased productivity and sustainability in agriculture could reduce the demand for clearing forests and savannas to meet local agricultural and economic needs.

Before undertaking any changes in land uses and agricultural management, it will be important to make detailed assessments which evaluate the overall effect in terms of net sequestration or release of GHG into the atmosphere. There is presently an urgent need to launch useful long-term (>10 years) field experiments and demonstration projects in Africa. Existing data are not readily comparable, it is uncertain how large amounts of carbon could be sequestered, findings are site-specific, and it is unclear how well the sites represent wider areas. Soil depth and measurement period should be comparable across experiments. To develop suitable CDM projects, it will be important to conduct experimental trials designed to generate reliable and comparable data. Estimating all environmental and economic benefits and costs would be necessary. Projects should provide opportunities for experimentation and learning. By comparison to forestry project, there has been little research on costs and benefits of soil carbon sequestration. The World Bank's Soil Fertility Initiative might be useful in this respect.

Finally, under certain circumstances it seems necessary to look beyond soils in order to sequester sufficiently large amounts of carbon. Some soils in Africa have a very limited potential for carbon sequestration and only through tree-based systems would it be possible to sequester reasonably large amounts of carbon. Useful ways of combining agricultural and forestry systems should therefore be identified. But agroforestry should be regarded as a means to combine agricultural production with tree growing rather than promoting trees as a substitute for agricultural crops.

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