Session 3:
Mitigating Climate Change through Restoration of Degraded Land

Soil Carbon Sequestration through Desertification Control

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Abstract

Desertification, a natural process, is exacerbated by anthropogenic activities. It reduces soil productivity, jeopardizes food security, impairs environment quality, accelerates global warming and exacerbates global security risks. Degradation of soil and vegetation aggravates the emission of greenhouse gases into the atmosphere. The biophysical processes of soil and vegetation degradation are closely interlinked by social, economic and political factors which govern land ethics and are prone to the tragedy of the commons. The annual rate of global emissions has increased from 1.3%/yr in the 1990s to 3.3%/yr for 2000-2006, with dire consequences to global warming and environment quality. While global emissions must be reduced by 2030 through a range of options, by 100 billion tonnes (Pg) to stabilize atmospheric abundance at 650 ppm of CO_2 eq., and by 250 Pg at 490-540 ppm of CO_2 eq., there exists an opportunity to utilize C sink capacity of the degraded and desertified terrestrial biosphere. Desertification control and restoration of degraded soils and ecosystems has a potential to sequester 0.9-1.9 Pg C/yr. However, conversion to a restorative land use and adoption of recommended management practices remain a challenge for the resource-poor farmers and small land holders of the regions prone to desertification. Thus, creating another income stream through the trading of C credits may provide the much needed financial support to invest in land restoration.

Introduction

Anthropogenic emissions between 1850 and 2006 are estimated at ~ 330 Pg C due to fossil fuel combustion and cement manufacture, and an additional 158 Pg from land use change and soil cultivation. Furthermore, the emissions due to fossil fuel combustion have increased from 7.0 Pg/yr in 2000 to 8.4 Pg/yr in 2006 (Canadell et al., 2007). The average growth rate of emissions due to fossil fuel combustion and cement manufacture have increased from 1.3%/yr in the 1990s to 3.3%/yr for 2000-2006. Consequently, the atmospheric concentration of CO_2 in 2006 of 381 ppm is the highest since several million years (Canadell et al., 2007). Total anthropogenic emissions are estimated at 7.0 Pg C/yr for 1970-1999, 8.0 Pg C/yr for 1990-1999, and 9.1 Pg C/yr for 2000-2006. For the same periods, the atmosphere has absorbed 3.1 Pg/yr, 3.2 Pg/yr and 4.1 Pg/yr, respectively. The capacity of the natural sinks (e.g., land, ocean) was 56.3% for 1970-1999, 60.0% for 1990-1999 and 54.9% for 2000-2006 (Table 1). The capacity of land sink alone for the same period was 28.1%, 27.2% and 24.2%, respectively. Thus, the capacity of land sink has progressively declined, probably due to an increase in the extent and severity of desertification and degradation of world soils and ecosystems.

Table 1. Recent trends in the global carbon budget (Recalculated from Canadell et al., 2007).

Parameter	1970-1999	1990-1999	2000-2006
I. Sources (Pg C/yr)			
Fossil fuel combustion	5.6	6.5	7.6
Land use change	1.5	1.6	1.5
Total	7.1	8.1	9.1
II. Sinks (Pg C/yr)			
Atmosphere	3.1	3.2	4.1
Ocean	2.0	2.2	2.2
Land	2.0	2.7	2.8
Total	7.1	8.1	9.1
Capacity of All Natural Sink (%)	56.3	60.0	54.9
Capacity of Land Sink (%)	28.2	27.2	24.2

Desertification and the degradation of soil and vegetation in drylands impacts about 1 billion people worldwide in more than 100 countries (Doolittle, 1997). It leads to a decline in soil and environment quality and perpetuates the food deficit (Lu, 2001). Of the 6.31 billion hectares (Bha) of the world's dryland area, 5.17 Bha or 69% is presumably desertified to some degree through degradation of either vegetation, soil or both (UNEP, 1991; 1992). Of the desertified land area, 1.016 Bha is desertified cropland and rangeland and 2.57 Bha of degraded vegetation in the rangeland. In comparison, Oldeman and Van Lynden (1998) estimated that the area affected by desertification is 1.137 Bha. Of this, 0.489 Bha is severely/extremely desertified. Similar to the estimates of land area affected by desertification, those of the rate of desertification also vary widely. The annual rate of desertification is estimated at 5.83 million hectare (Mha) or 0.132%/yr of the world's drylands (UNEP, 1991; Mainguet, 1991). Even if these statistics are nearly correct, it is hard to understand the reasons for a nearly lack of concrete action by the global community.

Some consider that the process of desertification is set in motion by the "tragedy of the global commons" (Hardin, 1968). It is the overgrazing of the common rangelands and indiscriminate deforestation of the common woodlots which lead to the mining of soil fertility, depletion of the soil carbon pool, and over-exploitation of the groundwater leading to denudation of the vegetation cover, acceleration of soil erosion by water and wind, and increase in the frequency and intensity of dust storms. As Aristotle said, "What is common to the greatest number gets the least amount of care. Men pay most attention to what is their own: they care less of what is common". Indeed, desertification is a biophysical process of aridization of a region, but it is driven by a strong interaction between natural resources (e.g., soil, vegetation, water, climate) with socio-economic and political factors. The principal cause of desertification, land misuse and soil mismanagement leads to a progressive decline in soil quality, a breakdown of structural properties, an increase in susceptibility to crusting and compaction, an increase in losses of water by surface run-off and evaporation, acceleration of soil erosion by water and wind, depletion of plant nutrients and soil organic matter (SOM), and the overall decrease in the net primary productivity (NPP).

One of the consequences of the process of desertification is the loss of soil carbon (C) pool, some of which is emitted to the atmosphere as carbon dioxide (CO_2) (Lal, 2001; 2003). The soil C pool, comprising soil organic C (SOC) and soil inorganic C (SIC), is highly dynamic and can be a source of atmospheric CO_2 under the conditions of inappropriate land use and soil mismanagement ($C_{output} > C_{input}$). Therefore, desertified soils have a much lower SOC pool than the undegraded soils under the protective cover of the natural vegetation. Thus, restoration of degraded/desertified soils can reverse the process and lead to an increase in the soil C pool along with replenishment of soil fertility and an increase in activity and species diversity of soil fauna and flora (Lal, 2001).

Comparing the 1990s with 2000-2006, the emission growth rate of CO_2 has increased from 1.3% to 3.3%/yr because of the growth in the world economy and its C intensity (Canadell et al., 2007). There is also a long-term increase in the airborne fraction of the CO_2 emissions, an indication of the decline in the efficiency of the natural CO_2 sink of land and ocean (see Table 1). With the current and future threat of global warming, there is a strong interest in developing cost-effective and efficient strategies of sequestering atmospheric CO_2 with ancillary benefits. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) has estimated that the cumulative emission reduction needed between 2000 and 2030 is 100 Pg to stabilize the atmospheric abundance of CO_2 at 650 ppm of CO_2-eq, and 250 Pg to stabilize at 490-540 ppm CO_2-eq (Bohannon, 2007). The strategies identified to reduce these emissions include the following: cuts in greenhouse gases other than CO_2, emission capture and storage, energy conservation and efficiency, renewable energy including nuclear and biofuels, and C sequestration in terrestrial sinks including the terrestrial biosphere. Therefore, the objective of this paper is to describe factors affecting desertification and assess the potential of desertification control and restoring degraded soils and ecosystems to sequester C and mitigate global warming.

1. Global Warming and Desertification

There is a close link between global warming and desertification. The process of desertification is likely to be exacerbated by the current and projected global warming. The historical evolution of human awareness about the impact of the atmosphere on the earth's climate has been vividly explained by Weart (2003), and is briefly summarized here. The process of global warming has been recognized since 1783, when a volcanic fissure in Iceland erupted, pouring out several km^3 of lava in the atmosphere. A peculiar haze dimmed the sunlight over Western Europe for months. During his visit to Europe in 1783, Benjamin Franklin noticed the unusual cold that summer and speculated that it might have been caused by the volcanic fog (Weart, 2003). The energy budget of Earth's atmosphere was first estimated by Joseph Fourier in the 1830s. He argued that the sun's radiation is balanced by the invisible infrared radiation emitted by the earth, and that the earth's atmosphere somehow keeps some of the radiation in. John Tyndall (1862) observed that some of the trace gases in the atmosphere (CO_2, CH_4, H_2O vapour) were opaque to infrared radiation while O_2 and N_2 were not (Weart, 2003). Tyndall argued that these trace gases in the atmosphere have the same effect as does the glass in the greenhouse, and thus named these as "greenhouse gases". John Tyndall argued that the atmosphere acts as a barrier to outgoing radiation and raises temperature at the Earth's surface (Tyndall,1863). Swante Arrhenius (1896) and his colleague Arvid Högbom (1897) estimated that doubling the CO_2 concentration in the atmosphere would raise the earth's temperature by 5-6 °C (Weart, 2003). It was Högbom who estimated that the temperature in the Arctic regions would rise about 8-9°C if the carbonic acid increased 2.5-3 times. Alfred Wallace, in his book *Man's Place in the Universe* made two important observations: (i) the atmosphere (areal ocean) allows sun rays to pass but its constituents (water vapour and carbonic acid) intercept and absorb the sun's radiation; and (2) an increase in Earth's temperature may cause some extremely violent and intense storms to uproot even the largest of trees (Wallace,1903). The second observation is extremely relevant to Hurricane Katrina that hit New Orleans, USA in 2005 and Cyclone Sidr that hit Bangladesh in 2007. In his lecture to the Royal Metropolitan Society, Guy Stewart Callender (1938) hypothesized that carbon dioxide produced by industry is responsible for global warming. *Time Magazine* carried a lead article entitled the "Warmer World" in its 2 January 1939 issue which stated that "Gaffers who claim that winters were harder when they were boys were quite right" (Time, 1939: 27). The theme reappeared in the 26 March 2006 issue of *Time Magazine* with a lead article entitled "The Tipping Point" which stated that "Polar ice caps are melting faster than ever…More and more land is being devastated by drought…Rising waters are drowning low lying communities…By any measure, Earth is at the Tipping Point" (Kruger, 2006). The dynamic nature of Earth's climate has influenced the evolution of human and other biota on earth (Linden, 2006). Climate change can change civilization and human history (Fagan, 2004).

While the greenhouse effect is a natural process, essential to life on earth, it is the acceleration of the natural process by anthropogenic activities that leads to the so-called 'global warming'. The rate of increase in temperature by global warming is >0.1 °C/decade, so that the ecosystems cannot adjust to this rapid change. For each 1° C increase in global temperatures, the vegetation zones may move pole-ward by 200-300 km. The global warming observed since the middle of the 20th century, estimated at an increase of earth's mean temperature by 0.6 ± 0.2 °C and a sea level rise of about 18 cm, is attributed to an increase in atmospheric abundance of trace gases (CO_2, CH_4, N_2O) since the Industrial Revolution occurred around 1750 (IPCC, 2001; 2007). While the principal source of anthropogenic emission is fossil fuel combustion, the impact of land use and land use change and of soil cultivation on the emission of trace gases in the atmosphere cannot be overemphasized. Ruddiman (2003; 2005) argues that a trend of increase in atmospheric concentration of CO_2 began 8000 years ago, and that in the case of CH_4 emission 5000 years ago, corresponding with the dawn of settled agriculture with attendant deforestation, soil cultivation and the spread of rice paddies and raising of cattle. Ruddiman (2003) estimates the pre-industrial emissions at 320 Pg primarily from terrestrial sources (biota and soil) caused by deforestation, land use change and soil cultivation. By comparison, emissions from land use change are estimated at 136 Pg between 1850 and 2000 (IPCC, 2000), and 158 Pg between 1850 and 2006 (Canadell et al., 2007). In contrast, emissions from world soils caused by ploughing and tillage are estimated at 78 ± 12 Pg (Lal, 1999). It is the depletion of the SOC pool that has created the C sink capacity in world soils because most cultivated/agricultural soils contain much less SOC pool than their potential capacity. The magnitude of depletion of SOC pool from agricultural soil is exacerbated by soil degradative processes (e.g., erosion, salinization, physical and chemical degradation). Furthermore, depletion of the SOC pool leads to declines in soil quality and the ecosystem services it provides (Lal, 2004).

2. Carbon Sequestration in World Soils and Terrestrial Ecosystems

Carbon sequestration involves the capture and secure storage of atmospheric C that would otherwise be emitted or remain in the atmosphere. Carbon sequestration is important because: (i) as of yet, there are no non-carbon fuel sources as viable alternatives to fossil fuels; (ii) there is a need to stabilize atmospheric abundance of CO_2; (iii) it is necessary to restore ecosystem services of degraded soils/ecosystems; and (iv) there is an urgency to advance/achieve global food security. It is in this regard that identification of an appropriate C sink (e.g., geologic, oceanic or terrestrial) is important. Choice of an appropriate sink and of a C sequestration strategy depends on numerous characteristics including the following: (i) high sink capacity; (ii) long residence time or stability of the sink; (iii) low cost of C sequestration; (iv) either a positive or minimal negative environmental impact; and (v) numerous ancillary benefits.

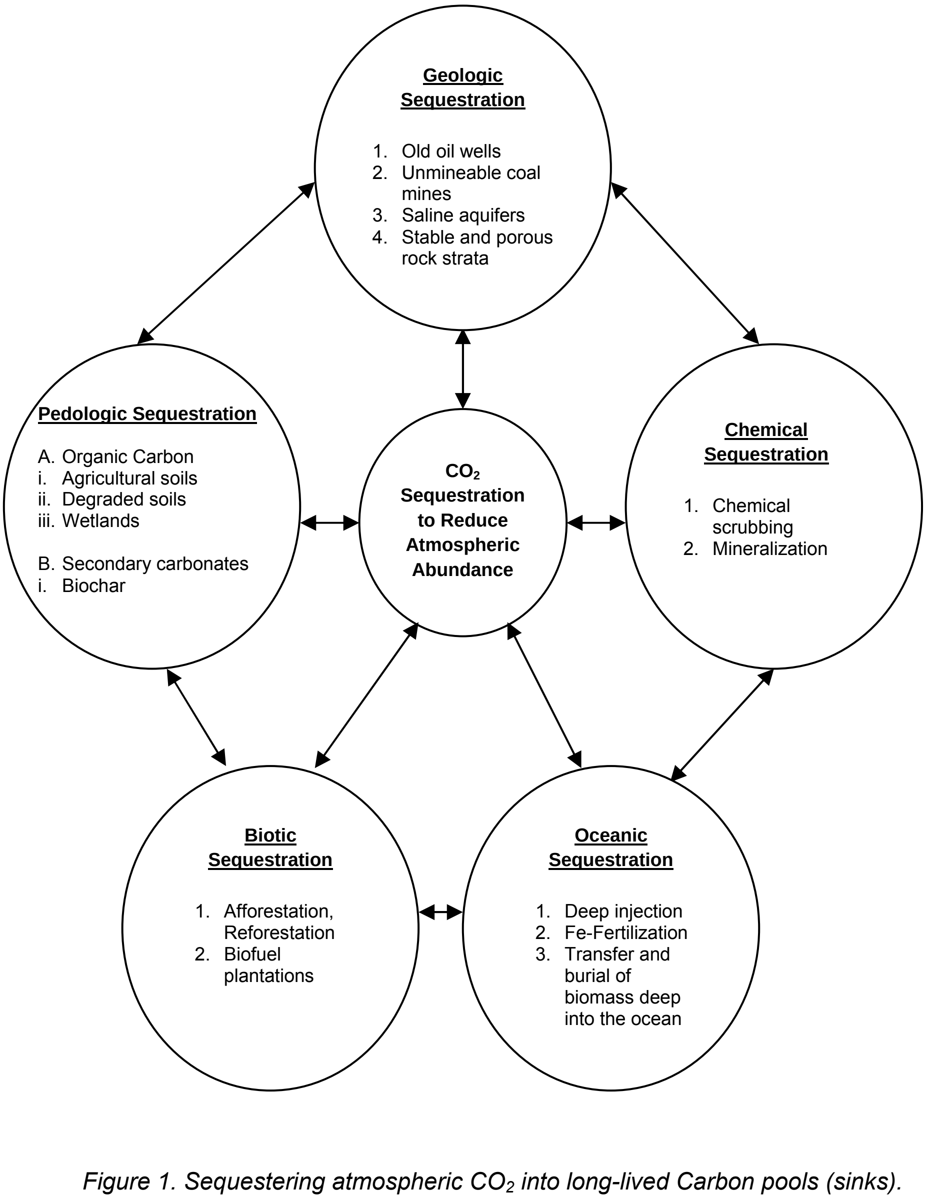

Figure 1. Sequestering atmospheric CO_2 into long-lived Carbon pools (sinks).

Figure 1 outlines numerous potential C sinks and strategies to transfer atmospheric CO_2 into these sinks. There are pros and cons for each strategy (Socolow, 2005; Lal, 2008). Geologic sequestration involves the capture, purification, compression and transport of industrial CO_2 into stable geologic strata 2000-3000 m below the soil surface. Traditionally, injection of liquefied CO_2 into old oil wells is recommended to enhance oil recovery (EOR) and old coal seams to enhance coal bed methane (CBM). Geologic sequestration also involves the injection of liquefied industrial CO_2 into stable rock strata and in saline aquifers where it may be converted into stable minerals. The chemical sequestration involves chemical scrubbing of industrial CO_2 and its mineralization or conversion into carbonates of calcium (Ca) and other metals. Similar to geologic sequestration, oceanic sequestration involves the injection of industrial CO_2 into the ocean several metres below the surface (Lal, 2008). In addition to injection, oceanic sequestration also involves the use of iron (Fe) fertilization to enhance biomass production and conversion of atmospheric CO_2 into biomass by enhancing the growth of oceanic biota. Some have argued that burying biomass (crop and forest residues) deep into the ocean can also sequester C because of no microbial decomposition. Both geologic and oceanic sequestration strategies have high sink capacity. However, these strategies are expensive, have some adverse environmental impacts, and the stability of these sinks is questionable. Thus, measurement and verification are necessary to validate that there is no leakage.

In contrast to the engineering techniques of geologic and oceanic sequestration, biotic sequestration is a natural process. It is based on the natural process of photosynthesizing atmospheric CO_2 into carbohydrates, cellulose, lignin and eventually into humic substances. Annually, about 120 Pg of CO_2-C is converted into biomass by the photosynthetic process. However, most of it is returned back into the atmosphere either by plant respiration (60 Pg) or by soil respiration (60 Pg). The rationale for emphasizing the biotic over the engineering strategies (e.g., geologic and oceanic) of C sequestration lies in the concept that if even 7% of the 120 Pg of naturally photosynthesized C can be retained in the biosphere, it can effectively offset the current level of industrial emissions estimated at 7.6 Pg C/yr during 2000s (WMO, 2006; Canadell et al., 2007).

There are several components of terrestrial/biotic sequestration (Figure 2). Important among these are: (i) forest biomass both above and below ground; (ii) wetlands; (iii) bioenergy plantations; and (iv) soil/pedologic C pool. Important strategies of soil/pedologic sequestration are the conversion of biomass-C into stable humic substances and organic-mineral completes or into secondary carbonates in agricultural soils, degraded soils and wetlands.

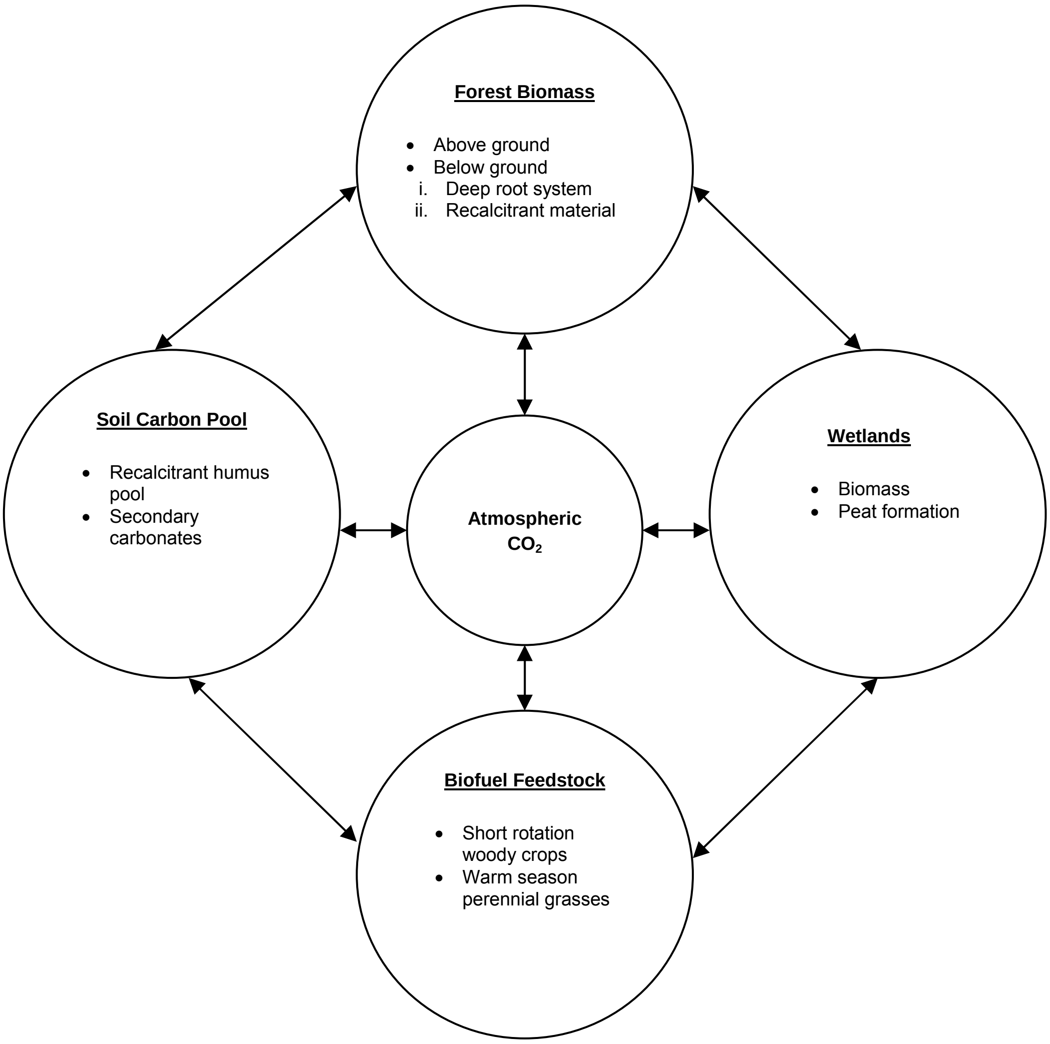

Figure 2. Strategies of terrestrial carbon sequestration in biota and soil.

Some promising techniques of C sequestration into the terrestrial biosphere are outlined in Figure 3. Recommended management practices for soil C sequestration include: (i) erosion control and restoration of degraded/desertified soils; (ii) conservation/no-tillage in association with the use of crop residue mulch and incorporation of cover crop in the rotation cycle; (iii) use of manure and techniques of integrated nutrient management; (iv) adoption of agro-forestry and diversified/complex farming/cropping systems; and (v) improving pastures and using controlled grazing. Establishing biofuel plantations or the afforestation of marginal soils is a viable strategy for C sequestration in terrestrial ecosystems.

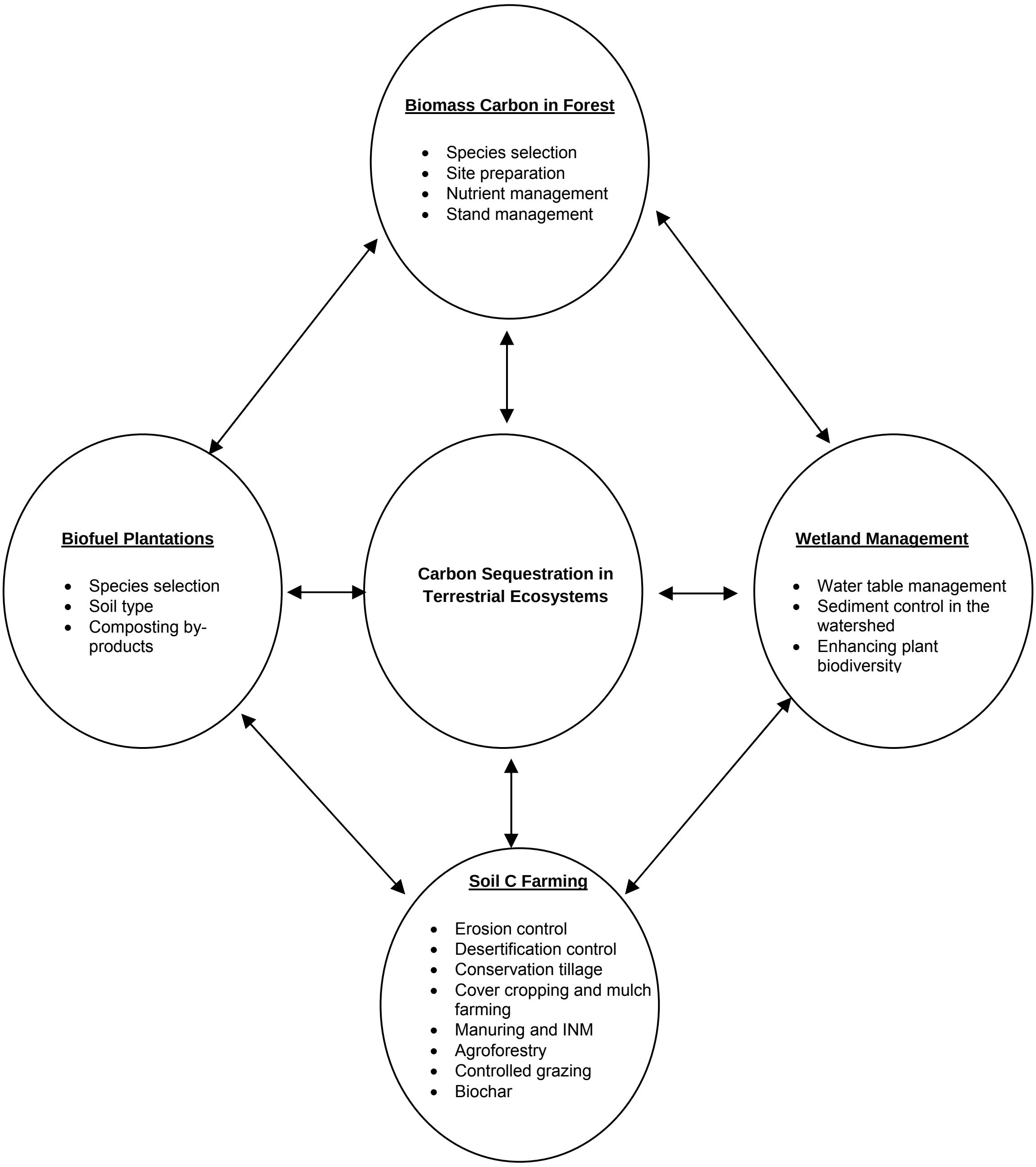

Figure 3. Technological options for carbon sequestration in terrestrial ecosystems.

Enhancing SOC pool has numerous ancillary benefits, especially with regards to the following: (i) improvement of soil structure and tilth; (ii) reduction in soil erosion hazard; (iii) increase in plant available water; (iv) improvement in plant nutrient reserves and recycling; (v) increase in availability of food for soil biota; (vi) purification and filtration of water; (vii) increase in biodiversity; (vii) improvement in crop/biomass yields; and (ix) offset of fossil fuel emissions with a positive impact on the mitigation of global warming. Above all, soil C sequestration is a cost-effective and natural process. It makes soil a living system. The importance of managing and sustaining SOC pool to enhancing soil quality and sustaining agronomic/biomass productivity has been recognized for centuries if not millennia (Thaer, 1809, 1811; King, 1911, 1926; Semple, 1928; Albrecht, 1938; Howard, 1940, 1952; Jenny, 1941; Allison, 1973; Feller, 1997).

3. Nutrient and Water Requirements for Carbon Sequestration in Soil and Terrestrial Ecosystems

The CO_2 from the atmosphere is just one component converted into carbohydrates, just as carbon in the biomass is only one of the essential building blocks of humus. Other essential components for converting CO_2 into biomass are water and plant nutrients for photosynthesis, and nitrogen (N), phosphorus (P) and sulphur (S) and other elements for converting biomass into humus. Water and essential nutrients/elements are in short supply, especially in deserts and desertified ecosystems, and are a major constraint to enhancing terrestrial C sequestration in these regions. For example, C:N, C:P and C:S ratio is 80-100, 200-400 and 300-600, respectively, in the biomass versus 10-14, 40-60 and 60-80 in the humus. Thus, an additional supply of N, P, S and other elements is essential to converting biomass C into stable humic substances. Himes

(1998) calculated that sequestration of 10 Mg of C into humus would require 28 Mg C contained in 62 Mg of oven dry crop residues, 833 kg N, 200 kg P and 142 kg S. Availability of these elements would produce about 17.3 Mg of humus leading to an increase of SOC concentration by 0.7% in the 20 cm soil layer. Lal (2004) estimated that agricultural soils have a potential to sequester 0.6-1.2 Pg C/yr. Requirements for the realization of this potential include 3.7-7.4 Pg of oven dry biomass, 0.05-0.1 Pg N, 0.012-0.024 Pg of P and 0.0086-0.0172 Pg of S. The total amount of humus thus created (1.0-2.1 Pg) would offset atmospheric CO_2 by 0.28-0.56 ppm. It is important to realize that a positive soil nutrient budget is essential to enhancing SOC pool (and plant nutrients) while growing biomass is a major constraint that must also be addressed.

Regions with a high potential of sequestration in soils and terrestrial ecosystems are those which have depleted/degraded soils and denuded vegetation cover. There are large areas of sub-Saharan Africa (SSA) and South Asia (SA) where the SOC pool has been mined out by land misuse and soil mismanagement. Henao and Baanante (2006) estimate that in SSA, depletion rates of nutrients range from 30-40 kg to 60 kg of NPK/ha/yr. The International Fertilizer Development Center (IFDC) (2006) estimates that about 95 Mha of arable land in Africa have reached such a state of degradation that only huge investments could make them productive again. Restoration of these degraded soils and ecosystems would enhance the terrestrial C pool, improve ecosystem services, offset fossil fuel emissions, and advance the much needed food security while breaking the perpetual agrarian stagnation.

4. Removing Crop Residue for Biofuel Production

In an attempt to produce C-neutral fuel, crop residues are being considered as a source of ligno-cellulosic biomass (Somerville, 2006; Kennedy, 2007). However, crop residues and other bio-solids produced from agro-ecosystems have numerous competing uses (e.g., soil amendment, feed, industrial raw material, construction material and fuel). Removal of crop residues for uses other than as soil amendment can adversely affect soil quality and disrupt numerous ecosystem services (Wilhelm et al., 2004; Blanco-Canqui and Lal, 2007). Indiscriminate harvest of crop residues amounts to robbing Peter to pay Paul (Lal and Pimentel, 2007), and has severe environmental consequences especially with regards to accelerated erosion (Pimentel and Lal, 2007). The environmental costs and those related to a decline in agronomic productivity are large and appropriate to support the argument that “there is no such thing as a free biofuel from crop residues” (Lal, 2007). Doornbusch and Steenblik (2007) argue that biofuel as a cure is worse than the disease. Indeed, there are numerous adverse impacts of harvesting crop residues on soil quality (Figure 4). Residue removal adversely impacts soil’s physical, chemical and biological quality. The latter is jeopardized because residues provide food substrates for soil biota. To live, an organism must have a source of energy. Soil organisms, essential to maintaining their quality, also need food. The latter comes from returning biomass/crop residues to the soils.

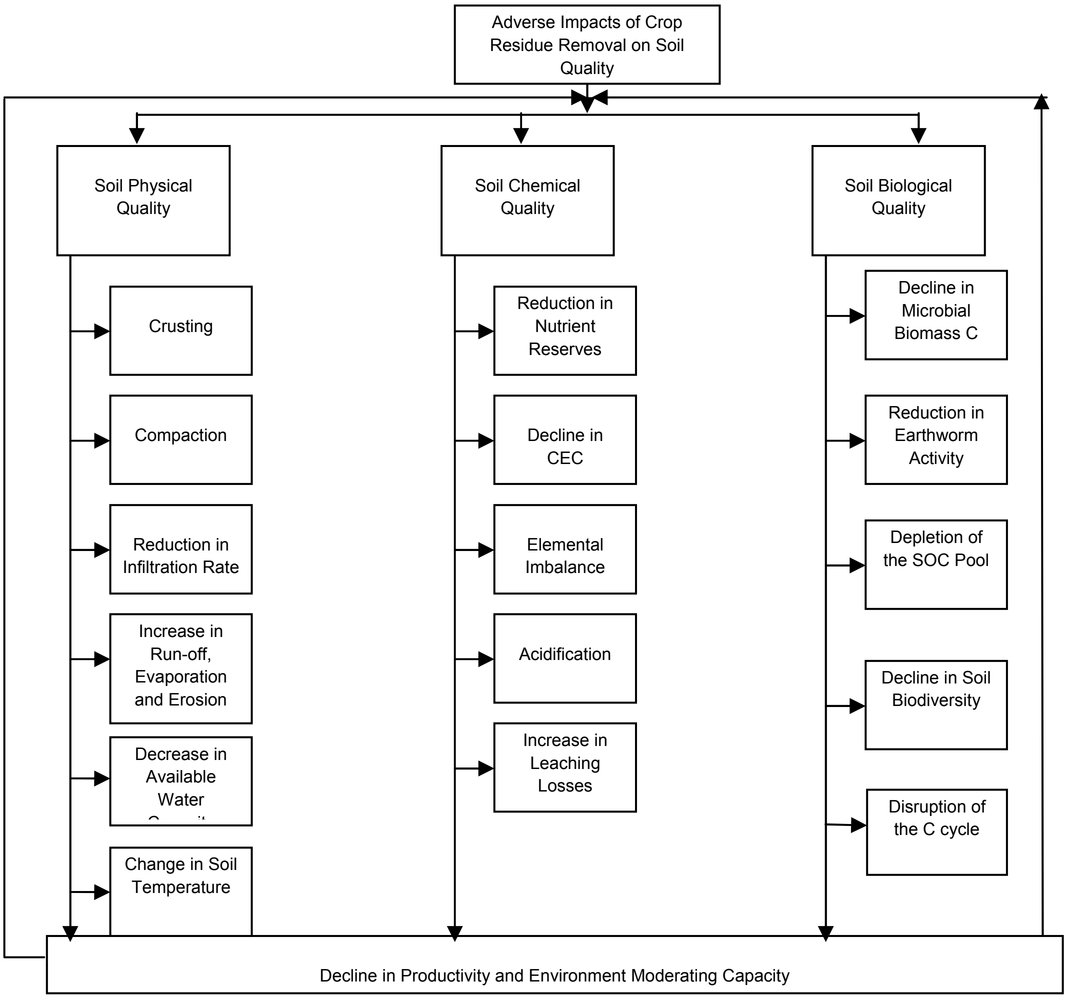

Figure 4. Adverse impacts of harvesting crop residues on soil and environment quality.

5. The Land Ethic

The severe problems of soil degradation and desertification, driven by socio-economic and political forces, require the establishment of land ethics and a strong need for promoting stewardship of soil resources. As Leopold (1981) states "there is as yet no ethic dealing with man's relationship to land and to animals and plants which grow upon it. Land, like Odysseus' slave girls, is still property: the land relation is still strictly economic, entailing principles but not obligation" (Leopold, 1981: 218). Human society has learned some critical lessons and has developed a collective wisdom that can guide us to sustainable management of soil resources. We do now recognize that the environmental issues are really problems affecting all of humanity. For example, exhaust fumes and soot from traditional cooking fuels can cause respiratory diseases, fossil fuel emissions lead to global warming, acid rain kills trees and fish, deforestation causes flooding and land slides, chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) deleteriously impact the ozone layer, and mono-cropping reduces biodiversity. Indeed, there is a price attached to all the goods and services provided by earth's resources. The choice of any strategy reflects the value that humans place on the benefits yielded by a given technological advance and the harm associated with the hazard. Therefore, it is prudent to carefully balance the benefits versus the hazards to objectively assess the ecological footprints and not just the economic value. It is important to science to address the commons. Identifying technological responses to alleviate these problems and rewarding those who no longer desecrate these commons is a prudent strategy. It is urgent to identify and implement the corrective feedbacks that are needed to keep custodians honest by creating environmental monitoring systems and taking responsibility for maintaining, controlling and disseminating the information among all stakeholders. As Adlai Stevenson (1965) states "we travel together like passengers on a little spaceship, dependent on its vulnerable reserves of air and soil; all committed for our safety, to its security and peace, preserved from annihilation only by care, the work, and, I will say, the love we give our fragile craft". As an ancient Vedic scripture states: "upon this handful of soil our survival depends. Husband it and it will grow our food, our fuel and our shelter and surround us with beauty. Abuse it and soil will collapse and die, taking humanity with it".

6. Offsetting Fossil Fuel Emissions through Desertification Control and Reclamation of Desertified Soils and Ecosystems

Desertification control involves the removal of the causes (e.g., deforestation, excessive grazing and misuse, mining soil fertility by extractive farming practices leading to negative nutrient balance, etc.). Important strategies of desertification control include soil and water conservation, enhancing SOC pool, and strengthening nutrient/elemental recycling mechanisms. Important strategies include the establishment of vegetal cover on denuded soils, application of soil amendments, and conversion to restorative land use (e.g., improved pasture with controlled grazing, afforestation, conservation farming).

Lal (2001) estimates the potential C sequestration through desertification control at 0.9-1.9 Pg C/yr over a 25-50 year period (Table 2). Furthermore, improvements in soil quality through restoration of degraded soils has the important benefit of achieving food security by improving agronomic/biomass production and increasing use efficiency of input (e.g., fertilizers, irrigation, energy). Lal (2006) estimates that increasing SOC pool in degraded/desertified soils by 1 Mg C/ha/yr can increase global food production by 26-30 million Mg/yr.

Table 2. Potential of desertification control and soil restoration to sequester C (adapted from Lal, 2001).

Process	Potential of C sequestration (Pg C/yr)
Emission reduction through erosion control	0.25
Restoration of eroded soils	0.25
Restoration of physically and chemically degraded soils	<0.01
Reclamation of salt-affected soils	0.3
Agricultural intensification on undegraded soils	0.015
Fossil fuel C offset through biofuel production	0.4
Sequestration of secondary carbonates	0.2
TOTAL	1.4 (0.9-1.9)

Soil C sequestration is a common thread that links several UN Conventions (Figure 5). Indeed, SOC sequestration is truly a win-win-win strategy. An important strategy of desertification control is the establishment of biofuel/bioenergy plantations on degraded soils. Global energy uses, in the equivalent of millions of tonnes of oil, were 250 in 1800, 800 in 1900, and 10,000 in 1990. It is increasing rapidly, especially in the developing economies of China, India, Brazil, Mexico, South Africa, etc. Furthermore, there is a scarcity of high-quality soil for all competing uses. Blum (2002) reports that global land resources include 2.4% of class I land supporting 6.1% of the world population, 9.5% of class II and III land supporting 19% of the population, 33.3% of class IV, V and VI land supporting 53.6% of the population, 9% of class VII land supporting 11.5% of the population, and 45.3% of class VIII and IX land supporting 13.1% of population. Indeed, only 12% of the land surface is suitable for food and fibre production, 24% for grazing, and 31% for forest plantations. As much as 33% of the land is unsuitable for any kind of sustainable land use (Blum and Eswaran, 2004). Furthermore land area available for agricultural uses is progressively decreasing because of conversion to urban and industrial uses. The unsustainable land use has exacerbated the problem of soil degradation because of the depletion of soil organic carbon and nutrient pools, soil erosion and desertification.

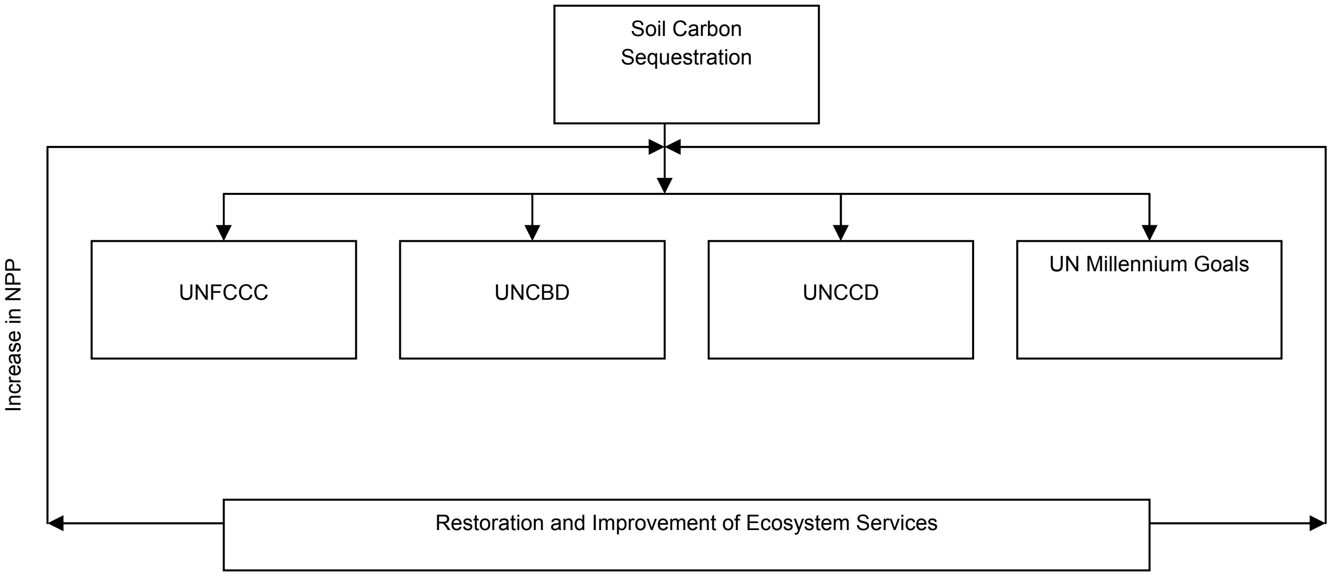

Figure 5. Link between soil organic carbon sequestration, UN Conventions and UN Millennium Development Goals.

The establishment of bioenergy plantations on some degraded/desertified soils may be a viable option. Choice of appropriate species or short rotation woody perennials or highly productive grasses can meet the needs to produce renewable sources of energy while restoring degraded soils and ecosystems. However, the use of soil amendments and installation of techniques for soil and water conservation are essential to sustainable production of biomass through energy plantations established on degraded soils.

7. Trading Carbon Credits and Promoting Soil Restoration and Desertification Control

Carbon sequestered in soils and biota can be traded as a farm commodity, and thus used to generate another income stream for resource-poor farmers. The price of C at the Chicago Climate Exchange is rather low, at about \$2/Mg of CO_2 (\$7.33/Mg of C) in December 2007. However, the price is likely to increase if the Kyoto Treaty endorsed by the Bali convention is endorsed by the world community. For example, the price of C is much higher in the European Exchange than it is in the Chicago Climate Exchange because European Union (EU) countries have accepted a mandatory cap on emissions. In addition to providing extra income, even at a low rate of US\$ 2-5/ha/yr including sequestration in soil and biomass, the concept is ecologically and politically sound. The farmers and land managers are being compensated for the ecological services provided to the world community. It would be even more appropriate if the payments for C sequestration are linked to the adoption of a restorative land use and modern innovations in soil and crop management. Any investment in soil restoration which enhances C sequestration and improves soil quality would also reverse the degradation trends, control desertification and increase biomass production while improving the environment.

The CO_2 arithmetic that would facilitate cap and trade has been presented by Broecker (2007). Rather than incremental reductions, Broecker (2007) proposes the concept of a “carbon-pie”. It is estimated that for each 4 Pg of C burnt, the atmospheric concentration of CO_2 rises by 1 ppm. For 9.1 Pg of total emissions (Table 1), we are increasing the annual concentration by about 2.3 ppm (9.1 ÷ 4 = 2.3). This 4:1 ratio, however, may change over time. Thus, if the IPCC fixes the desirable limit of CO_2 concentration at 540 ppm (Bohannon, 2007), then the size of the carbon-pie is at 640 Pg [(540 ppm – 380 ppm) x 4 Pg/ppm = 160 x 4 = 640 Pg]. The size of the carbon-pie would decrease with a decrease in the upper limit of the CO_2 concentrations in the atmosphere. Once the size of the carbon-pie is determined, each nation is allocated its share based on population and other factors. Those nations which consume more than their share of the pie would have to purchase a share from other nations which save their portion of the pie by conserving or finding alternate sources of energy.

There is another set of calculations needed to calculate the cost of using the carbon-pie in addition to national allocation. The total CO_2-eq emitted by a nation is computed as the sum of all gases [(CO_2x1) + (CH_4 x 21) + (N_2O x 310) = CO_2-eq] (Walsh, 2007). Total CO_2-eq is then multiplied by the estimated price of C offset (e.g., \$50/Mg for the European Exchange). If a nation wishes to purchase C credits from Niger, Ghana, Nepal etc., for example, it would have to pay that country accordingly.

In addition to the computations shown above, the commodification of soil C is based on developing a methodology for credible measurement of C pool in soil/biomass and its change over a known period of time. Rather than the traditional measurement of C concentration (%) in the plough layer, measurements for trading of C credits require assessment of C pool (Mg/ha) in the soil solum (1 m or more) and change in the pool (kg/ha/yr) over a short period of 1-2 years. Furthermore, these measurements need to be made over a landscape, watershed or regional scale. A protocol needs to be developed to facilitate trading of C sequestered in restored soils and ecosystems.

Conclusions

The decline in natural land-based sink capacity between 2000-2006 may be attributed to degradation and desertification of soil and biota. The serious problem of desertification, a consequence of the “tragedy of the global commons”, is driven by socio-economic and political factors. The problem is exacerbated by harsh climates (e.g., Iceland) and fragile soils (e.g., sub-Saharan Africa). Principal factors include land misuse and soil mismanagement, such as extractive farming practices based on mining soil fertility and depleting soil organic matter reserves. The scarcity of prime soil resources, competing uses of soil for urban and industrial purposes, and rapidly increasing population in developing countries necessitate restoration of degraded soils and ecosystems. Carbon sequestration in terrestrial ecosystems (e.g., soils and biota) is an important strategy of restoring degraded and desertified soils. Compared to geologic and oceanic strategies, terrestrial sequestration is cost-effective and a natural process with numerous ancillary benefits. Establishing bioenergy plantations and involving the choice of appropriate species and use of suitable bio-solids and amendments are important to restoring desertified soils while producing renewable energy. The constraint of adopting recommended technologies because of the lack of resources available to small land holders can be alleviated through the trading of C credits and commodification of C sequestered in soils and biota. Soil C sequestration generates another income stream for farmers through trading of C credits. The concept of carbon-pie and payments according to the cost of offset of the desired CO_2-eq can facilitate commodification of terrestrial C.

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Carbon Finance and the Millennium Development Goals: Potentials, Opportunities and Barriers

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Introduction

According to the Millennium Ecosystem Assessment (MA) (2005), large areas of land in the developing world have experienced significant degradation, driven principally by the conversion of land to socially sub-optimal cultivation practices that do not internalize medium- and long-term social costs. While global statistics should be considered uncertain, it is estimated that approximately 10% of the world's land surface is severely degraded (Hassan et al., 2000; FAO, 2007; Reynolds et al., 2007).

The advent of the market in carbon has raised the possibility of harnessing carbon finance as a mechanism for rehabilitating degraded lands through the capture ('sequestration') of atmospheric carbon in biomass and soils. Nabuurs et al. (2007) summarize several studies indicating that afforestation, reduced deforestation and forest management can potentially offset 1.3-13.8 Gt of carbon dioxide equivalent (CO_2e)/year through 2030, a figure compatible with that provided by Kauppi et al. (2001). Presenting these figures in a slightly different manner, Sedjo and Marland (2003) conclude that biological sinks have the potential to capture 10-20% of anticipated net fossil fuel emissions between now and 2050. Although these figures are much lower than offsets from industrial sources, their Millennium Development Goals (MDGs) benefits earn them further consideration.

Carbon sequestration has significant intrinsic benefits. First, it is the only climate change mitigation activity that addresses the problem of greenhouse gases (GHGs) already in the atmosphere. While it is undeniable that the bulk of global efforts should consist of emissions reductions, it makes little sense not to take steps to remove GHGs already emitted. The observed rise in global mean temperature since 1900 has thus far been approximately 0.8ºC (IPCC, 2007). However, when the full temperature impact of today's greenhouse gas concentration of 430ppm CO_2e is realized, temperature may increase by at least another 0.5ºC (Meehl et al., 2005), and possibly by as much as 1ºC (Wigley, 2005). Unlike other mitigation activities, carbon sequestration can actively serve to reduce this residual 'commitment to climate change' (Wetherald et al., 2001).

Second, carbon sequestration has the potential to open the carbon market to poor, rural communities in which industrial mitigation projects cannot be established. These communities already suffer exclusion from the global economy; to preclude their participation in the carbon economy from the outset would serve only to further isolate and impoverish them.

Finally, carbon sequestration represents the interface between climate change adaptation and climate change mitigation. That is, it simultaneously couples minimization of the negative economic, social and environmental consequences of global warming (through increasing the sustainability of rural livelihoods and enhancing ecosystem resilience) with limitation of the climate change itself (through reducing atmospheric greenhouse gas concentrations).

However, though these claims have been repeatedly made, questions have been raised as to whether such projects can, in fact, increase the productivity, resilience and sustainability of farming and natural systems, thereby increasing rural incomes and preventing rural exodus. In other words, can carbon sequestration projects sustainably finance the simultaneous benefits of climate mitigation, climate adaptation and sustainable development?

The economic viability of land rehabilitation is often marginal, especially in developing countries where the marginal cost of investment in rehabilitation is far higher than abandoning the degraded land and exploiting new lands (Glenn et al., 1993). Official Development Assistance (ODA), environmental finance such as the Global Environment Facility (GEF) and government investments are often insufficient to cover the capital-intensive costs of land rehabilitation. Approximately US$ 2 billion in ODA is available to combat desertification (Global Mechanism, 2007). Even using a conservative figure of US$ 100/ha for the costs of land rehabilitation, applied over the 300 million ha of severely degraded land identified by Oldeman (1994), this results in a global rehabilitation cost of approximately US$ 30 billion, 15 times the level of available aid, without even including newly degraded lands.

This leaves us with one key question: can the carbon market add the necessary financing to make land rehabilitation an economically viable activity? Is carbon the 'holy grail' of land rehabilitation?

1. Restoring Land Capability

Many different strategies have been shown, under controlled conditions, to successfully rehabilitate degraded land, restore land capabilities and enhance the productivity of land. However, not all have been tested in real-world situations and not all are economically feasible.

Globally, there are 3 million km^2 of lands whose degradation is classified as 'severe and extreme' (Oldeman, 1994)[2], amounting to approximately 2% of the world's land surface. The estimated cost of their rehabilitation is extremely high,

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[1] Currently with the United Nations Environment Programme.

ranging from US$ 100 (degraded farmland) to US$ 40,000 (large-scale mining) per ha, depending on the severity of chemical and bio-physical losses in the soils (DOC, 2007; Datta et al., 2000; Le Houerou, 1996; Reij et al., 2005). These high costs present a formidable challenge to financing such rehabilitation through the carbon markets.

Consider a typical forestry approach to rehabilitation, using trees to stabilize and replenish the soil and the revenue from sustainable logging to cover the project's costs. Studies show that the supplemental value of a carbon layer to such a logging enterprise is very low. A temperate sustainable logging enterprise is estimated to provide US$ 300-2,660/ha/year in economic returns from timber harvests, compared with US$ 13-35/ha/year from carbon storage and sequestration, depending on carbon price (Vogt et al., 2005). Furthermore, there is an inescapable trade-off between timber revenue and carbon sequestration: maximizing the former will create losses for the latter (Kramar et al., 2005). The Afforestation/Reforestation (AR) projects approved by the Clean Development Mechanism (CDM) to date suggest that carbon revenue can increase the internal rate of return of the underlying project over a large range: between 0.5 and 7 percentage points, with the higher uplifts correlated with large-scale operations (Neeff and Henders, 2007; Yemshanov et al., 2007). In some cases, such as in Panama, potential small scale CDM Afforestation-Reforestation (AR) projects are not an attractive financial alternative for communities (when compared to current land uses of cattle raising and cropping), unless other sources of income are added (Coomes et al., 2007).

The economic value-added of improving dryland agricultural systems in developing countries is generally low. For example, in Sudan, millet, sorghum, sesame and groundnuts cost more to produce than the income from selling the product, while only 'high-end' products such as watermelon and karkadé generate a positive income. The value-added of carbon sequestration from improved agriculture in such settings (for example, through improved manure application, rotation of crops and fallow, and agro-forestry) is reported to increase the income of the farmer by only 1-4%, and little more in developed country settings (FAO, 2004; Morand and Thomassin, 2005). At current prices for carbon, this increment is too low to provide an incentive for farmers to engage in carbon projects.

But there is some evidence that shifting land use in order to restore its original (functional) capability may be a potentially viable strategy, from both environmental and socio-economic perspectives. In such projects, rehabilitation of lands that have been degraded as a result of conversion to socially sub-optimal uses (e.g. rangelands being converted to cropping, or forests being converted to grazing) show sufficient incremental carbon sequestration to warrant further investigation.

In this paper, three of the most promising land capability restoration project types are discussed. Estimated rates of carbon sequestration can be used as a proxy measure to evaluate their financial potential. However, we stress that since the financial viability of these strategies is not as yet certain, no firm conclusions can be drawn.

The three strategies are: the conversion of degraded cultivated lands into grassland or rangeland; the conversion of degraded croplands and pastures to forest; and the conversion of degraded farmland into agro-forestry systems. All three strategies aim to restore utilized (but nonetheless degraded) lands to their original ecological capability through land-use changes that also generate benefits for sustainable livelihoods and poverty alleviation.

1.1. Conversion of degraded cultivated land into grassland or rangeland

The Millennium Ecosystem Assessment concludes that between 1900 and 1950 approximately 15% of rangelands were converted to cultivated systems, and that a somewhat faster conversion has taken place in the last five decades during the so-called 'Green Revolution'. Transformation of rangelands and sylvo-pastoral dryland systems to croplands is known to increase the risk of desertification (Millennium Ecosystem Assessment, 2005).

This land capability restoration strategy foresees the restoration of former rangelands and grasslands by means of carbon-financed land-use change, soil and water conservation for rapid re-vegetation, sylvo-pastoral techniques for land capability restoration, and sustainable animal husbandry systems.

Studies indicate (Conant et al., 2001) that the conversion of degraded cultivated land to grassland pasture can result in net annual increases of soil carbon of 3% and more. In West Africa, this represents an annual sequestration rate of 0.3-0.8 tC/ha/year (Batjes, 2001). Other studies show that conversion of cropland to grassland can potentially sequester 1.2-1.7 tC/ha/year from soils alone (FAO, 2004; Freibauer, 2003; Vagen et al., 2005). Soils typically account for 70-90% of the total carbon sequestered in a grassland ecosystem.

A major concern for this type of land capability restoration approach is that of 'leakage' – the displacement of pre-project land-use activities. If farmers who are displaced by a land rehabilitation project simply move elsewhere to continue to practice subsistence agriculture, the result is further land degradation and no net carbon sequestration benefits. Such leakage can be avoided by choosing sites where farmers already have incentives to convert from low-productivity cropping to high-productivity grazing, but lack the economic resources to do so. Carbon finance could be harnessed to actively assist them in making this land-use change, with a lower attendant risk of displacement.

Another concern often raised in the context of carbon sequestration projects is the risk that such projects will create untouchable 'carbon reserves', productive land that is no longer available to local communities. In fact, in the case of grazing land this concern is largely misplaced, as there is strong evidence to indicate that well-managed grazing actually results in

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[2] As noted in MA (2005) and elsewhere, the figures of Oldeman (1994) must be used warily. However, his breakdown of degradation into different classes remains unique and therefore represents a valuable source.

higher levels of carbon sequestration. Conant et al. (2001) found that grazing management typically leads to a 3% annual increase in soil carbon. Extensive pastoral management can, therefore, be actively integrated as a positive addition to a sequestration programme, thus ensuring sustainable development benefits.

1.2. Conversion of degraded croplands and pastures to forest

This land capability restoration strategy foresees the use of afforestation and reforestation techniques, many of which are CDM-eligible, for conversion of degraded croplands and pastures. It includes compatible income-generating activities, such as fruit and medicinal production, selective logging, selective animal production, biofuel production and cropping. The potential for such cropland restoration is significant: 220 million hectares of forest land were converted to food production between 1975 and 1990, typically with adverse environmental consequences (FAO, 2000).

One CDM-AR project underway in Albania will sequester 0.9 tC/ha/year (above- and below-ground carbon) over approximately 6,000 ha, by planting trees in degraded pastures (CDM-AR-PDD Albania, 2005). Since the project lands are communal and owned by the state (to which local communities have only usufruct rights), it is unlikely that the communities will have ownership rights over the carbon credits generated. However, as the project is linked to a larger World Bank-sponsored Natural Resources Development Project (NRDP), it is expected that there will be further benefits to the local population, including employment, enhanced fodder productivity on arable land, the introduction of improved breeds of livestock, and improved alternative pastures.

A study of a conversion of unimproved pasture to forested stands of mixed native and non-native species in Puerto Rico found that, in addition to significant carbon sequestration in above-ground biomass, the soil continued to act as a carbon sink and accumulated significant additional carbon (Silver et al., 2004). Afforestation produced a net gain of 33 tC/ha in soil carbon over a 55-year period, in addition to 80 tC/ha in above-ground biomass.

Under the right conditions, afforestation of pasture lands can entail a soil carbon sequestration rate of 0.6 tC/ha/year, in addition to sequestration in above-ground biomass of approximately 1.5 tC/ha/year. In total, therefore, this type of land rehabilitation activity can yield approximately 2.1 tC/ha/year (even disregarding the carbon embodied in underground root systems), a rate that can be expected to persist for at least 50 years.

There is considerable debate as to whether, and how, the current CDM rules and procedures concerning AR should be revised and improved. One of the concerns is that under the current Small-Scale Simplified Modalities and Procedures, and faced with the prevailing market price for credits, the costs of implementing small-scale carbon projects represent a significant fraction of the revenues subsequently generated: very little annual income would actually reach the low-income land owner (Schlamadinger et al., 2006).

Another concern is that the sustainable development benefits of these AR projects are likely not very high. Given the (appropriately) strict requirements of the approved CDM project methodologies to limit ‘leakage’, there are significant disincentives for project developers to execute projects in areas with large/poor rural populations. It is likely, therefore, that the carbon market will favour ‘quick fix’ monoculture projects that reliably sequester carbon but which generate few sustainable development benefits – and which may, in some cases, cause active harm to local livelihoods, biodiversity and watersheds.

1.3. Conversion of degraded farmland into agro-forestry systems

This strategy foresees the conversion of unsustainable farming into sustainable agro-forestry systems, through inter-cropping, zero-tillage and other techniques for sustainable crop production; the introduction of live fencing, hedgerows and fruit trees; and selective harvesting of biomass (e.g. for animal production or biofuel). Agro-forestry encompasses a broad range of practices that incorporate trees into farming systems, such as shade-grown coffee plantations and ‘alley cropping’ systems using leguminous trees to fertilize annual crops such as maize.

Writing in 2001, Kauppi et al. concluded that, globally, agro-forestry systems had the potential to sequester and store 26 million tC/year by 2010. A further 391 million tC/year could be sequestered by 2010 if an estimated 630 million hectares of unproductive cropland and grassland were converted to agro-forestry. The six year delay since 2001 without a global agro-forestry programme must make us push these returns back until at least 2017, but the general conclusion that agro-forestry can make a significant double contribution to poverty alleviation and climate change mitigation still stands.

Montagnini and Nair (2004) estimate storage of carbon by the tree component in agro-forestry systems at 9 tC/ha in a semi-arid environment, 21 tC/ha in a sub-humid environment, 50 tC/ha in a humid environment and 63 tC/ha in temperate regions. Reporting for the IPCC, Sampson and Scholes (2000) estimate a ‘central’ carbon sequestration rate for agro-forestry of 3.1 tC/ha/year.

Studies in India on planting tamarind on degraded cropland have yielded a net above-ground carbon sequestration rate of 0.2 tC/ha/year, in addition to the income from the sale of fruit and green leaves. In Mexico, planting 133 trees (*Cedrela odorata*) as windbreaks around 1 ha farms has resulted in an average 0.4 tC/ha/year being sequestered above-ground (PlanVivo, 2008).

While these estimates provide some boundaries for assessing the financial viability of agro-forestry to sequester carbon, much will depend on the particular project application and context. But the intrinsic characteristics of agro-forestry make it an attractive strategy to deploy for restoring land capability in situations where cropland degradation has set in. In addition to the carbon benefits, it can enhance and diversify food and income streams in the form of fruit, vegetable, oil, spices, medicine, timber and craft wood, and enhance the productivity of annual crops such as maize, cassava and rice through restoring ecological functions and services.

2. The Potential for Harnessing Carbon Finance

The commodification of carbon through trading of carbon credits under the Kyoto Protocol and alternative ('voluntary') market mechanisms represents a potential source of revenue for restoring land capability. By doing so, carbon markets offer the potential to deliver the triple benefits of climate change mitigation, enhanced resilience to adapt to climate change, and sustainable livelihoods.

However, the number of bio-carbon projects selling on the market at the moment is far lower than the potential suggests. Current market conditions, as well as a less-than-enabling environment, are proving to be disincentives to developing carbon sequestration projects that work with small land-users. There are several key barriers, outlined in more detail below, that increase the transaction costs of small-scale projects, to such an extent that transaction costs account for a significant fraction of potential revenue. As much of the transaction cost burden is attributable to fixed costs, there is a clear economic incentive to 'dilute' such costs through project expansion: project investors will tend to favour large-scale, privately-owned sequestration projects over small-scale producer/local land user-owned projects. The sustainable development benefits of such large-scale projects may not be very high, and, in some cases, may result in exploitation and expropriation of the rights of poor farmers and herders.

Under current conditions, carbon revenue alone is unlikely to significantly enhance the financial returns from small-scale, high sustainable development projects. But when combined and sequenced with other potential revenue streams, the 'carbon layer' might be sufficient to transform an unattractive project into a financially viable one, offering a suite of associated sustainable development benefits. Such additional revenue streams can arise from the underlying project (crop yields, animal production, timber and non-timber sales); from the addition of other income sources (such as Payment for Environmental Services (PES)); or from the addition of multiple carbon layers to the same project (e.g. combining carbon credits from bio-sequestration with carbon credits from biofuels such as *Jatropha spp.*).

3. Barriers in Efficient Carbon Financing

There are a number of barriers within the current CDM rules to efficient harnessing of carbon finance for restoration of land capability. The following outlines a few of these barriers.

3.1. Up-front costs and risks

All bio-sequestration projects are faced with high up-front investment costs (land, seeds, labour, etc.), delayed return on investment, low rates of return (compared with industrial sectors) and high perceived risks. Land-use projects with environmental and social components are often not sufficiently profitable to attract the financing required to kick-start the project cycle. Once implemented, these projects may provide carbon credits at very competitive rates, but they have difficulty attracting pre-operational private sector capital in order to advance through the various project cycle steps (Neeff and Henders, 2007). Unless smallholders are capable of accepting early losses or low profits, or unless there is low-cost credit available, smallholders are unlikely to adopt a new system incorporating a carbon element (Wise and Chaco, 2005).

Another factor of fundamental importance is the widespread lack of clarity, or lack of equity, in land and carbon ownership. Private ownership strategies for AR projects, while simpler and less risky than common ownership strategies, do not typically generate as many development benefits. On the other hand, common ownership may lead to unwieldy project management, may introduce a free-rider dynamic amongst participants, and may experience greater difficulties securing commercial credit to cover up-front costs.

3.2. Transaction costs

Attention should be paid to reducing the transaction costs associated with CDM Land Use, Land Use Change and Forestry (LULUCF) projects. Current approved technologies and methods for measuring carbon sequestration with the prescribed degree of accuracy are cumbersome, costly and time-consuming. Furthermore, there is generally insufficient capacity in developing countries to validate and verify LULUCF projects: consultants often have to be flown in from Europe or North America to conduct on-site inspections.

It is estimated that the costs for CDM AR project preparation lie between US$ 11,000-180,000, with additional costs associated with validation (US$ 6,000-80,000) and verification (US$ 15,000-25,000 per audit, performed every 5 years) (Krey, 2005; Neeff and Henders, 2007). These figures do not include search costs (finding a buyer), negotiation costs, or the cost of actually monitoring the carbon sequestered. Including undergrowth and soil in the monitoring system is often not economically viable, even where monitoring capacities are high, due to the spatially variable nature of these carbon pools, their relative inaccessibility and their dispersed-storage characteristics (Robertson et al., 2004). Economic modeling suggests that including soil carbon in the monitoring system is worthwhile only if verification costs are less than US$ 8.90 per hectare (Wise and Chaco, 2005).

Many transaction costs are fixed, producing significant production economies of scale and leading many to conclude that projects generating less than 50,000 tCO_2e annually will be unable to compete in the global market (e.g. Capoor and Ambrosi, 2006; Krey, 2005). A valuable policy response to such observations would be to promote project bundling (aggregating) institutions, such as single-desk sellers or producer co-operatives. Pooling mechanisms are typically used to manage risk, and there is a long history of product pooling among small-scale resource producers such as Indian rubber tappers (Zant, 2001), Ivoirian cocoa farmers (Lloyd et al., 1999) and western Canadian wheat farmers (Biggs et al., 2006). Increased scale of production and risk distribution are achieved through such aggregation and the ability of such institutions to participate in international markets and adjust pricing behaviour in the face of uncertainty has been well documented (Tucker, 2001, Zant, 2001). Bundling is desirable because it allows many relatively fixed costs (especially those associated with project design, verification, negotiation and finding a buyer) to be spread over a larger number of carbon offsets than could be generated by a single farmer.

3.3. CDM requirements

The issue of non-permanence (i.e. the potential for carbon sinks to release some or all of their carbon) is a critically important one for projects that sequester carbon for land rehabilitation. Both the type of ‘reversibility event’ and its consequences vary considerably. Some events (e.g. drought) may kill trees but leave them standing with most of their carbon intact over the short- and medium-term. Trees uprooted by storms, however, decompose quickly and are often utilized for fuel wood. Some events, such as earthquakes and drought, are difficult to predict, while others, such as seasonal flooding or fires, can be forecast fairly easily.

For predictable events, risk can usually be reduced during the project design stage: site selection, management practices and species planted will all mitigate certain risks. Risks that cannot be addressed in these ways can be addressed through financial mechanisms such as insurance, weather derivatives or institutionally-determined caps on how many credits can be sold. The most common method (and the one enshrined in CDM regulations) is to require a conservative estimation of a project’s carbon potential at all phases of project planning, monitoring and validation. Conservatively estimating a project’s carbon potential at the outset can implicitly incorporate the effect of reversibility events.

At an institutional level, the CDM addresses the permanence problem through the issuance of ‘expiring Certified Emission Reductions (CERs)’, which expire after varying durations according to differing accounting procedures: short-term (temporary CERs (tCERs)) or long (long-term CERs (lCERs)). It must be recognized, however, that community-based, development-oriented projects tend to reduce the permanence risk relative to large-scale, corporate-driven projects by making permanence an element of long-term livelihood strategies rather than a short-term financial investment. While even the most carefully managed project is vulnerable to stochastic events, incorporating permanent forest cover into the life of a community improves – at the very least – the chances of immediate reforestation after a local reversibility event.

Soil organic carbon is currently eligible for crediting under CDM LULUCF rules. However, it is credited in the form of expiring CERs, just as is above-ground carbon. This is despite the fact that the risk of non-permanence is much lower for soil carbon than it is for above-ground biomass: as long as the land-use and environmental conditions do not change, soil carbon can effectively be preserved as a permanent sink. The global potential to sequester soil carbon is very high, estimated to be between 0.4-1.2 Gt per year (Lal, 2004). This potential could more easily be achieved if soil carbon were to be credited using permanent CERs or, at least, an instrument with greater permanence than expiring CERs.

Furthermore, the CDM permits AR projects only on areas without forest since 31 December, 1989. This is to prevent perverse incentives being established whereby land owners could generate carbon revenue by removing virgin forest and replacing it with secondary forest plantations. However, the 1989 cut-off date penalizes landscapes where genuine efforts at reforestation have been attempted and results in ecological discontinuities that undermine contemporary rehabilitation efforts. Two AR CDM methodologies (AR-AM0002 and AR-AM0005) have been approved within the past year that acknowledge this problem. They explicitly permit areas upon which failed, failing or size-restricted forestry activities have been initiated to be included in CDM-eligible AR projects so long as any pre-project AR sequestration is incorporated into the project baseline. The majority of approved AR CDM methodologies do not include this option, however, limiting the ability of project developers to execute projects in areas where AR has failed before. This acts as an inappropriate limit on potentially poverty-alleviating development.

4. Relaxing Carbon Market Regulations

The effects of removing (or lowering) the barriers outlined above are evident from a brief examination of markets with fewer regulations than the CDM, such as the voluntary over-the-counter (OTC) offset market and the Chicago Climate Exchange (CCX).[3]

Investors participate in the voluntary markets in order to demonstrate corporate social responsibility and environmental integrity. Since these markets are not subject to international treaties and market participants do not face legal emission caps, the accounting procedures and project monitoring regimes are more relaxed than for the CDM, and the transaction costs are commensurately lower (Hamilton et al., 2007).

In this less regulated environment, 36% of credits sold (by volume) are sourced from forestry projects – as opposed to fewer than 1% of CERs in the CDM. However, three important caveats must be noted. First, 73% of total credits traded in the OTC and CCX markets are sourced from the United States and Europe from heavily forested regions where many of the ‘low-hanging fruit’ (such as hydrofluorocarbon (HFC) decomposition projects) that have dominated the CDM are unavailable. As

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[3] The following discussion is based on the results of surveys overseen by New Carbon Finance and the Ecosystem Marketplace published by Hamilton et al. (2007).

such, it is not clear how forestry projects would compete against less expensive options. Second, three-quarters of the forestry credits in these markets were sourced from large-scale projects generating more than 100,000 tCO_2e per year – projects that may not necessarily provide significant development opportunities. Third, the voluntary markets are small relative to the regulated markets, equivalent to only 2% of the volume of the EU Emissions Trading Scheme and 5% of the volume of the CDM. This suggests that the absolute volume of forestry credits in these voluntary markets is approximately the same as that currently produced in the CDM.

Nonetheless, these results suggest that in an environment devoid of low-hanging fruit with more relaxed project regulations, AR projects can flourish relative to other project types.

5. Recommendations

To achieve the 'triple' benefits of climate change mitigation, enhanced adaptation and sustainable livelihoods, greater attention should be paid to projects that restore land capability. In particular, emphasis should be placed on projects that encourage re-conversion of degraded land to its highest ecological capability, notably cropland to rangeland in arid systems, and degraded pastureland to sustainable forest management in humid systems. Community participation and ownership of such projects is a key element to ensuring sustainable development as well as to enhancing the permanence of the carbon sequestered.

The carbon market can significantly catalyze land rehabilitation if the economic and social barriers are lifted and market incentives are created that foster greater equity. It is recommended that barriers to participation in the market by small-scale landholders be lifted. Furthermore, modification of certain CDM rules would make a large difference to the financial viability of land restoration projects. Of particular note are the following:

a) Market transformation through relaxation of the eligibility requirements under CDM LULUCF.
  (i) Allow the inclusion of more land-use types, ecosystems and project-types into the LULUCF category.
    - Expand definitions from forests to also include also grasslands and other biomes.
    - Avoid emissions through fire management in grassland and forests.
    - Devise rules to allow reforestation and revegetation on land deforested after 1989, subject to safeguards to prevent system gaming.

  (ii) Expand the role of soil carbon in the CDM.
    - Soil carbon is far more permanent than above-ground biomass. This should be recognized in project crediting, which should not be in the form of expiring CERs, but something more akin to a permanent CER. Since permanent CERs fetch a higher price in the market than expiring CERs, the financial viability of soil sequestration projects would be enhanced.
    - Alternatively, the CDM would grandfather temporary CERs and convert them to permanent CERs after an extended period of validation, if necessary at a discount (Bosquet, 2006).

  (iii) Create economies of scale in AR while promoting small-holder production.
    - Revise upward the limit on small-scale AR projects from 8,000 tCO_2e/year to 30,000 tCO_2e/year (Schlamadinger et al., 2006) or 40,000 tCO_2e/year (Bosquet, 2006).
    - Promote bundling of AR projects, allowing the 'bundle' of projects to surpass the 50,000 tCO_2e/year glass ceiling while preserving the use of the Small-Scale Simplified Modalities and Procedures.

  (iv) Closely monitor the 1% cap on carbon mitigation volumes that can be sourced from LULUCF.
    - While the current volume of AR projects is only an estimated 1/20 of this 1%, if the cap begins to become binding (and thereby limiting to the development potential of the CDM), it should be removed so as to encourage rural poverty alleviation.

b) Enhancement of the Enabling Environment
  (i) Analysis of financial viability of different land restoration strategies, combining different income sources.
    - The potential for combining and sequencing different income sources (agricultural commodities, biofuels, multiple carbon layers, etc.) to increase the profitability of land restoration projects needs to be analyzed in greater detail before it can be promoted in developing countries. ODA funding could prove instrumental in undertaking such detailed financial and social analysis of the 'carbon business model' for restoration of land capability.

  (ii) Increase the availability of credit to cover up-front costs.
    - ODA funding should be encouraged for start-up funds to help defray investment costs, and to help absorb market risks in the early stages of project preparation and implementation. Ultimately, with market transformation and enhanced enabling environments, the conditions should become conducive for commercial loans to cover such up-front costs.

  (iii) Public investment in research and development of reliable and low-cost technologies for measuring soil carbon.

  (iv) ODA funding should increase capacities of smallholders, project developers, government entities and other intermediaries to engage equitably in the carbon market.

Conclusion

There is significant potential for harnessing carbon finance for restoration of land in such a way as to ensure triple benefits from climate mitigation, climate adaptation and sustainable development. However, this potential cannot be realized under current market conditions.

CDM rules and transaction costs for AR sequestration projects have skewed the market towards projects that are large-scale and favour private developers. Such projects tend not to produce high sustainable development outcomes for the poorest of the poor, and the simultaneous 'triple benefits' are often not evident. Projects associated with other land-use types, such as grasslands, wetlands and cropland, that could potentially generate very high sustainable development benefits, are not eligible under current CDM rules. Furthermore, the difficulties that private-sector operatives often encounter in managing risks, in establishing tenure rights via land markets and/or engaging in negotiations with national/regional governments and local communities have resulted in a volume of AR carbon credits well below the 1% cap LULUCF credits permitted under CDM rules.

A few key changes to the CDM rules would generate greater incentives, reduce risk and create the right market conditions for smallholder and small-scale carbon sequestration projects, offering triple-benefit outcomes. These changes can be summarized as follows:

- Market transformation through relaxation of the eligibility requirements under LULUCF CDM: Allow the inclusion of more land-use types, ecosystems and project types into the LULUCF category; increase the size threshold of small-scale AR projects; expand the role and eligibility of soil carbon in the CDM.

- Enhancement of the enabling environment: Public investment in detailed financial and social analysis of the 'carbon business model' for restoration of land capability; public investment in the research and development of reliable, low-cost technologies for measuring bio-carbon; improved availability of credit to cover up-front project development costs; enhanced capacities of smallholders, project proponents, government entities and other intermediaries to engage equitably in the carbon market; promotion of project bundling and aggregating institutions to allow the rural poor to take advantage of economies of scale.

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Harnessing Carbon Finance for Land Restoration: Can it be Done and Will it Work?

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Introduction

For smallholder farmers in developing countries, the costs of combating land degradation and establishing more sustainable farming systems include: the labour spent on land contouring; the establishment of living soil protection barriers or soil improving shrubs; the lower yields (in early years) when converting from burning to non-burning cultivation systems; the foregone production from areas where the soil is simply too fragile to use for agriculture; and, the effort of organising and regulating the use of common grazing and fuel wood production areas.

1. The Inefficiency of Aid to More Sustainable Farming

It is difficult to quantify these costs (or barriers) in monetary terms, especially in subsistence economies where wage rates are seasonal and depend on social relations as much as on economic circumstances. One innovative smallholder farmer in southern Mexico who had been the first in the village to adopt non-burning maize production told me how he had been mocked by his neighbours for three years before some started to follow his lead. However, on the basis of additional labour inputs required on yields forgone in early years, I estimate the total cost per hectare typically ranges from US$ 500-2000 (Dregne and Chou, 1992; De Jong et al., 1996). After incurring these costs, it may be several years before the benefits from soil improvement can be clearly appreciated.

Unfortunately, few aid-based programmes get anywhere near overcoming these cost barriers. First, it is not common for aid programmes to deliver financial assistance for land improvement activities directly to farmers; in most cases, the only physical resources delivered to farmers are inputs such as seed, fertiliser, or equipment. While these inputs may be welcome, they do not cover the costs mentioned above.

Second, most aid is delivered without any conditions attached. As one farmer said: “this government aid is like the rain; sometimes it falls and sometimes it doesn’t; there is nothing you can do about it; just hope for the best”.

Third, aid frequently creates dependency rather than stimulating productivity, organisational capability and enterprise (Moss et al., 2006; Brautigam and Botchwey, 1999). In many developing countries, farmers and village representatives expect to be paid to turn up to meetings to discuss local development – these “sitting fees” are a strong indicator of cynicism and dependency, for surely if people believed that going to a meeting would really make a difference to their lives then they would not need to be paid to turn up.

Finally, a large proportion of the aid directed toward sustainable land use never gets to where it could make a difference – it is either absorbed by bureaucracy, diverted elsewhere, or used up by aid organisations in workshops, consultancy fees, research or internal capacity-building. When finance finally does get through to grassroots organisations, it often arrives at the wrong time or with political strings attached. I recall, several years ago, having to spend several hundred thousand dollars of donor money on tree seedlings in two weeks because the reporting timeframes set by the World Bank were based on financial schedules, not on the seasons.

2. A New Hope – Carbon Finance for Environmental Benefits

Given the deep problems with using aid to address the problem of land degradation, it is not surprising that many organisations have become interested in the prospect of undertaking sustainable land management and ecosystem restoration activities with funding from the provision of environmental services, in particular the sequestration of carbon.

When the Clean Development Mechanism was finalised in Marrakech in 2001, the prospect of carbon finance through this flexible mechanism of the Kyoto Protocol being applied to protect and restore woodlands and agricultural systems appeared to offer a major new opportunity.

Unlike aid, carbon finance would be based on a measurable indicator of physical progress (increased carbon stocks in soil and above ground biomass). Unlike aid, environmental services represent a product in the form of an environmental certificate that can be produced and sold through markets, allowing communities to break free from dependency on handouts and the unequal relationship between donor and recipient. For many organisations, carbon finance appeared to provide a means of circumventing the established donor structures, the dreaded aid bureaucracy. Above all, carbon finance appeared to hold open the prospect of far greater financial flows than had previously been contemplated for this sector.

In 2001, hopes were high within the multilateral agencies: a United Nations Environment Programme (UNEP) press release stated: “a new chance to fight poverty, environmental degradation and chronic energy shortages across Africa is fast emerging as a result of the latest negotiations to fight global warming”. Later in the same year Pedro Sanchez, Director General of the World Agroforestry Centre (ICRAF) announced: "Africa must use this [CDM] as a new development opportunity. It opens the way for work that will not only have environmental benefits but ones related to health, hunger and poverty".

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[1] Currently with Ecometrica.

Around this time, the World Bank was establishing its BioCarbon Fund[2] – its aim: to kick-start the land use carbon market in developing countries with several hundred million dollars of initial investment. A new breed of carbon finance and development experts started to emerge: consultants, brokers and fund managers.

The Intergovernmental Panel on Climate Change produced over 500 pages of "Good Practice Guidelines for Land Use, Land Use Change and Forestry"; development agencies from Austria to United States Agency for International Development (USAID) funded training workshops all over the developing world on "how to access carbon finance for forestry and land use projects"; NGOs and academics debated the opportunities and threats associated with marketing the carbon attributes of forests. International verification companies hired new staff to audit forestry projects.

But while the rhetoric was spectacular and the workshops interminable, action on the ground was difficult to detect. Despite dozens of concept notes and project design documents flying between NGOs, consultants and carbon brokers, very few real projects appeared to be crystallizing. In 2007, while official enthusiasm for CDM forestry remained high within several of the multilateral agencies, it had become apparent to most organisations with practical experience in land restoration that "the Emperor had no clothes", or was at least, very scantily clad. Out of over 700 projects in the CDM, only one afforestation project in China had been approved, amounting to less than 0.1% of the total volume of reductions expected from the mechanism by 2012.

3. Breaking Down the Barriers

For those aware of the barriers to achieving sustainable land in rural communities in developing countries, it is not difficult to understand how the CDM excludes practical land use and forestry projects in developing countries by virtue of its design. Table 1 below contrasts the needs of farmers.

Table 1. Community needs for implementing sustainable land use activities versus CDM design features.

Needs	**CDM design**
Help with conserving and restoring a range of agro-ecosystems and woodlands.	Restricted to afforestation / reforestation of land deforested prior to 1990.
Up-front resources to cover costs over 3 to 5 years, before productivity payback is felt.	Retrospective crediting of carbon uptake over previous five years. Only very fast growing species grown on large scale likely to generate significant carbon revenue in five years.
Recognition of the multiple benefits of sustainable land use in the price of carbon from these activities (higher price).	Carbon credits discounted for risk through "temporary crediting" (lower price).
Long-term view of the carbon and sustainability benefits of sustainable land use.	Timeframe of CDM is currently limited to 2012. No certainty over market or rules beyond this date.
Simple process with minimal bureaucracy.	Highly bureaucratic and rigid process requiring approval by different national and international agencies. Deviation from project plan likely to result in loss of registration.
Ability to start small and scale up across a region, learning by doing.	Complex rules for bundling (grouping) of projects. Projects are considered to be of fixed size and duration.
Simple process for monitoring progress based on achievement of readily measured milestones.	Complex carbon quantification methodologies that are difficult to apply to developing country situations.

These fundamental differences between the needs of communities and the structure of the CDM explain why the mechanism has not worked for land restoration activities.

Efforts to overcome these structural problems by making minor adjustments to the scheme or by spending more time on training and CDM workshops have little prospect of success.

Does the failure of the CDM to provide a practical framework for promoting sustainable land use in developing countries mean that carbon finance should be written off as a promising model? I believe not.

Outside the bureaucratic confines of the CDM, there has been a small but innovative carbon market developing in the voluntary sector. The voluntary carbon sector has attracted a fair amount of criticism from the media and some environmental organisations and there have been some notable project failures and questionable marketing practices. Nevertheless, there have also been enough successes to indicate that where carbon finance is structured according to the needs of communities and small farmers, it can be highly effective at promoting the adoption of agroforestry systems, small scale forestry activities and community managed conservation areas.

The voluntary carbon sector is now starting to develop its own standards and guidelines and a number of certification schemes are under development – notably the Community, Carbon and Biodiversity Standard (CCBS)3, which was developed by The Nature Conservancy (US) in collaboration with a number of NGOs and research organisations; and the

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[2] See: http://carbonfinance.org/Router.cfm?Page=BioCF.

[3] See: http://www.climate-standards.org/index.html.

Plan Vivo System[4] developed by the Edinburgh Centre for Carbon Management (UK), El Colegio de la Frontera Sur (Mexico) and various community based organisations.

Reasons for the relative success of projects started in the voluntary carbon market include:

- the provision of up-front finance for the establishment of agroforestry and ecological restoration;
- relatively straightforward approval and contracting processes;
- flexibility, which allows projects to start small and then scale up through a process of replication; and,
- a growing community of project developers who are willing to share experiences and good practices.

Conclusion

The key weakness of the voluntary carbon market is its small size and lack of recognition by national governments and multilateral agencies. The sector needs to achieve scale and develop more credible governance structures. Above all, it needs to convince the international climate change community that the risk of project failure can be managed across a portfolio of activities. The climate change community for its part must accept the need to take on the risk of project failure – after all, if we do not even try then we are sure to fail.

I suggest that the UN agencies concerned with development, desertification, climate change and biodiversity should be much more proactive in engaging with the voluntary sector carbon initiatives for sustainable land use and forestry. At the very least, these activities can provide valuable lessons for the formal project mechanisms of the post-2012 climate change framework, and at most they could flourish into a major source of private sector engagement in sustainable land use in developing countries.

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[4] See: http://www.planvivo.org/.

Opportunities for Climate Change Mitigation in Agriculture: A Semi-Quantitative Assessment of Costs and Reductions Levels

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Abstract

Agriculture accounts for about 10-12% of the total global anthropogenic emissions of greenhouse gases (GHGs) or between 5.1 and 6.1 $GtCO_2e$ per annum. Emissions are increasing rapidly in agriculture, and between 1990 and 2005 these increases have been on the order of 17%. The objective of this paper is to assess the potential for climate change mitigation in the agricultural sector and to evaluate the costs of implementation of different options. In addition to examining the opportunities for emissions reductions, this paper examines the potential for creating sinks in agriculture and the costs of these options. There is potential for abatement of all sources, but with current technologies and the prevailing economic conditions, these potentials are all low. The analysis presented here suggests that 11-13% of non-CO_2 GHG and soil carbon emissions could be abated at reasonable costs. Sequestration, particularly through agroforestry, offers significant and cost effective means of reducing atmospheric concentrations of GHGs. The analysis suggests that the cost of sequestration could be as low as US$ 1.77 per tCO_2e, which is competitive with avoided deforestation and other forms of emissions abatement.

Introduction

Agricultural lands, comprising arable land, permanent crops and pasture, occupy about 40% of the earth's land surface (FAOSTAT[2]), and these lands are expanding. Most of the agricultural land is under pasture (~70%) and only a small percentage (<3%) are under permanent crops. Over the past four decades, an average of 6 million ha of forest and grassland has been converted to agriculture annually. Agricultural lands will continue to increase in the coming decades, with large increases expected in Latin America and Africa (Rosegrant et al., 2001). Emissions are expected to continue to increase due to increased demand for food as populations grow and with shifts in diets as societies in developing countries become wealthier and meat consumption increases.

There are two types of emissions from agriculture:

- Non-CO_2 GHGs from management operations = 6.2 Gt CO_2e
- Energy related CO_2 emissions (including emissions from manufacture of fertilizer) = 0.6 Gt CO_2e

Energy-related emissions are small from the sector, both in absolute magnitude and as a percentage of the emissions from the sector. They will not be considered further in this paper. Non-CO_2 GHG emissions are an order of magnitude greater than energy emissions. A third type of emissions from land-use change often associated with agriculture is also large, at around 7.6 Gt CO_2e.

In addition to reducing emissions from agricultural production, there are opportunities within the agricultural sector for additional measures to mitigate climate change. For example, there is a trend emerging for use of agricultural products to replace fossil-fuel based products, such as biomass energy, bio-plastics, and biofuels. This has the potential to reduce fossil-fuel emissions in the future, but emissions of non-CO_2 GHGs will increase, particularly as production systems intensify. Improved tillage practices have the potential to increase soil carbon storage and reverse the decline of soil carbon in newly converted lands. Thus, there is much interest in this practice both from the side of reducing energy use for tillage and for the potential for agricultural soils to be carbon sinks. In many cases however, infrequent tillage is practiced to control weeds, so the net long-term effects of this practice still needs to be evaluated.

Finally, although not considered in this report, changes in macroeconomic policy and regional patterns of production and demand lead to increased international trade in agricultural products. Increased transportation of agricultural products will lead to increased emissions.

1. Mitigation Potential and Costs

Mitigation potential in agriculture can be defined as either technical or economic. The technical potential for mitigation options in agriculture by 2030, considering all gases, is estimated at around 4500 Mt CO_2e by Caldeira et al. (2004). Smith et al. (2007) produced a higher estimate of between 5500 and 6000 Mt CO_2e. These estimates assume no economic barriers. The economic potential is, of course, considerably lower.

GHG emissions can be reduced by managing carbon and nitrogen more efficiently in agricultural ecosystems. Mitigation measures include agronomic measures such as improved crop varieties and different crop rotations. There are a series of soil management measures including improved nutrient management and reduced tillage that will reduce emissions and sequester carbon. Better residue and water management in rice can yield significant reductions of CH_4 emissions. For livestock, there are a wide range of practices associated with grazing, for example, land management, manure management and feeding that can reduce emissions and increase carbon sequestration. Finally, there are a number of changes in farming

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[1] Currently with the Centre for International Forestry Research.

[2] Please see http://faostat.fao.org/.

systems that can contribute to GHG mitigation, including the production of biofuels to reduce the use of fossil fuels and the adoption of agroforestry or improved pasture management for carbon sequestration.

The United States Environmental Protection Agency (USEPA) constructed marginal abatement curves for different regions of the world (USEPA, 2006) and different sub-sectors by estimating the carbon price at which the present value benefits and costs for each mitigation option equilibrates (present value of benefits = present value of cost). This produced a stepwise curve that reflects the average price of a tonne of CO_2e and reduction potential if a mitigation technology were applied across the sector within a given region. Costs included capital, or one-time costs, and operation and maintenance costs, or recurring costs. The calculation included a tax rate of 40% and used a 10% discount rate. Benefits included the intrinsic value of CH_4 as either a natural gas or as fuel for electricity or heat generation, non-GHG benefits of abatement (e.g. improved nutrient use efficiency), and the value of abating the gas given a GHG price. The break-even price calculations do not include transactions costs. All calculations were in US$ from the year 2000. More details on the construction of these curves can be found in the report.

Most of the abatement curves indicate negative costs for some level of abatement (Table 1). This means that some GHG emission reduction is already feasible and cost-effective. These activities have not yet been implemented because there are non-monetary barriers that need to be overcome. These opportunities are often referred to as “no regret” options. The curves all become very steep or even vertical at around US$ 30-45 per tonne of CO_2e. Thus, for this analysis, we will assume that this is the maximum economic level of abatement and we will calculate the abatement potentials at this level.

There are two ways to calculate the global aggregate abatement curves for agriculture: one could hold the cultivated area and number of animals constant, or one could hold production constant. Regional abatement curves were generated as was a globally aggregated abatement curve. Both types of curves were used to generate the summary of net reductions at different carbon prices in different regions of the world that is presented in Table 1. The global estimate, holding cultivated area and the number of animals constant, is approximately 7% of the net emissions from agriculture that could be mitigated at a net benefit or at no cost (< $0/$tCO_2e$) in 2000. At higher C prices, the abatement potential rises. For example, around 14% of the net emissions can be mitigated for less than $45/$tCO_2e$. Beyond this point, costs rise rapidly. The greatest potentials for negative- and low-cost reductions are in the Russian Federation, the non-OECD (Organisation for Economic Co-operation and Development) Annex I countries and the United States, and the European Union (EU)-15. Moderate amounts of zero- or low-cost reductions are available in most other countries or regions, with the exception of Africa, Brazil, India, and Japan.

Table 1. Potential total reductions ($MtCO_2e$) of emissions from agriculture for selected countries and regions with carbon prices at US$ 0, 30 and 45 per tCO_2e, with constant cropping area and constant herd size. Table adapted from USEPA (2006).

	2010			2020		
Country/Region	$0	$30	$45	$0	$30	$45
Africa	5.8	13.1	16.4	6.0	15.1	22.4
Annex 1	136.5	222.6	234.4	140.1	210.1	258.4
Australia/New Zealand	7.3	10.4	12.7	7.7	11.3	13.7
Brazil	9.3	16.9	16.9	10.1	18.3	20.6
China	61.7	111.5	114.7	55.2	106.0	121.4
Eastern	7.2	9.7	9.9	7.1	10.2	10.8
EU-15	24.0	38.5	39.3	23.9	36.4	43.5
India	7.1	41.9	42.5	7.2	44.6	48.4
Japan	1.3	7.6	7.7	1.4	7.8	7.9
Latin America/Caribbean	12.1	15.5	16.7	13.6	18.6	20.4
Mexico	3.5	5.6	5.6	4.3	6.8	7.6
Non-OECD Annex 1	38.1	62.0	62.2	38.4	43.0	67.8
OECD	97.5	162.1	173.8	100.4	168.5	193.8
Russian Fed	36.6	60.5	60.7	37.0	41.5	65.4
S&SE Asia	71.6	115.4	138.5	82.6	131.1	163.3
United States	49.8	80.4	87.9	51.1	86.6	97.0
World	313.6	552.1	596.5	323.1	559.4	681.8

To evaluate the investment required for abatement of soil C and non-CO_2 GHGs, the mitigation scenario was determined by the abatement curves presented above. For a number of gases, the maximum economic abatement potential corresponded to between US$ 30-45 per $MtCO_2e$. For several other sources, it was clear that additional reductions were feasible, but generally beyond the level of US$ 45 per $MtCO_2e$ the returns on the investment were decreasing rapidly.

Table 2 presents a sub-sector breakdown of the abatement opportunities and a projection through 2030. To project the reductions and the costs after 2020, which was the timeframe of the abatement curve analysis, the abatement curve for 2020 was used to calculate reductions and costs for 2030. Note that these curves assume constant harvested area and constant number of animals through time. Given the expected growth in population and the changes in diets to include more animal products as countries become more affluent, the estimates generated by this method are conservative. The projections for abatement costs range from US$ 16-20 billion (Table 2). Greatest reductions and greatest investments for these reductions are associated with mitigating emissions from rice. The smallest reductions and the smallest investments will be in the livestock sub-sector.

Table 2. Estimate of the reductions of emissions from non-CO_2 and soil carbon GHGs ($MtCO_2e$) and the investment needed to achieve these reductions ($ billion) between 2000-2030 at a cost of US$ 30 tCO_2e (2000).

	Year 2000		2010		2020		2030	
Sub-Sector	Reductions	Cost	Reductions	Cost	Reductions	Cost	Reductions	Cost
Cropland	172	7.74	183	5.48	168	5.04	180	5.39
Rice	200	6.00	226	6.79	238	7.14	243	7.30
Livestock	131	3.93	143	4.28	158	4.73	175	5.26
Total	529	15.88	596	17.89	631	18.92	684	20.51

2. Carbon Sequestration through Land Use Change and Management

The agricultural sector offers a number of mitigation opportunities, primarily through sequestration of atmospheric carbon, associated with land-use change and management. Agricultural lands also remove CH_4 from the atmosphere by oxidation, though less than forests, but this effect is small compared to other GHG fluxes (Verchot et al., 2000; Smith and Conen, 2004). Increased carbon stocks can be achieved through a change in land use to one with higher carbon stock potential (Lal, 2004; Albrecht and Kandji, 2003). The Intergovernmental Panel on Climate Change (IPCC) Special Report on Land Use, Land-Use Change and Forestry (2000) identified a number of categories of activities on agricultural lands that generate benefits:

- Agroforestry (including conversion from forests to slash-and-burn to agroforests after deforestation; conversion from low-productivity croplands to sequential agroforestry in Africa; integration of trees into farming systems and agricultural landscapes);
- Improved grassland management (including improved grazing management, fertilization, irrigation and use of improved species and legumes); and,
- Restoration of severely degraded lands (including salt-affected soils, badly eroded and desertified soils, mine spoils, and industrially polluted sites).

Two types of land management in the agricultural sector offer significant opportunities for carbon sequestration (Figure 1; IPCC, 2000): improved grassland management and agroforestry. For improved grasslands, high rates of sequestration can be achieved through introduction of more productive grass species and legumes. Improved nutrient management and irrigation can also increase productivity and sequester more carbon. About 60% of the grazing lands available for carbon sequestration are in non-Annex 1 countries.

Compared to other types of land-use change and compared to a number of management options, improved grazing land management and agroforestry offer the highest potential for carbon sequestration in non-Annex I countries. Agroforestry has such a high potential because it is the land use category with the second highest carbon density, after forests, and because there is a large area available for land use change. Grazing land management, despite the low carbon densities in these lands, has a high potential because of the large amount of land susceptible to this improvement (3.4 billion ha). Agroforestry also offers the potential for synergies between expanding the role of agroforestry in mitigation programmes and adaptation to climate change (Verchot et al., 2007). In many instances, improved agroforestry systems can reduce the vulnerability of small-scale farmers to inter-annual climate variability and help them adapt to changing conditions.

Other land use options, such as rehabilitation of degraded land and wetland restoration, have relatively low potentials, globally, to contribute to mitigation, although locally their potential may be significant. These low values are the combined result of low area availability and slow carbon accumulation rates.

A rigorous analysis of costs and mitigation potential does not presently exist in the literature and there is no basis to develop this at the moment. The IPCC (2000) Special Report presented an illustration of the potential of carbon sequestration to contribute to climate change mitigation. What I propose here is an expansion of the IPCC Special Report scenario, which will illustrate the potential for carbon sequestration in the agricultural sector and the costs of achieving that sequestration. The results of this analysis will only be semi-quantitative, but it is reasonable to expect them to be indicative of the order of the magnitude of the potentials and costs.

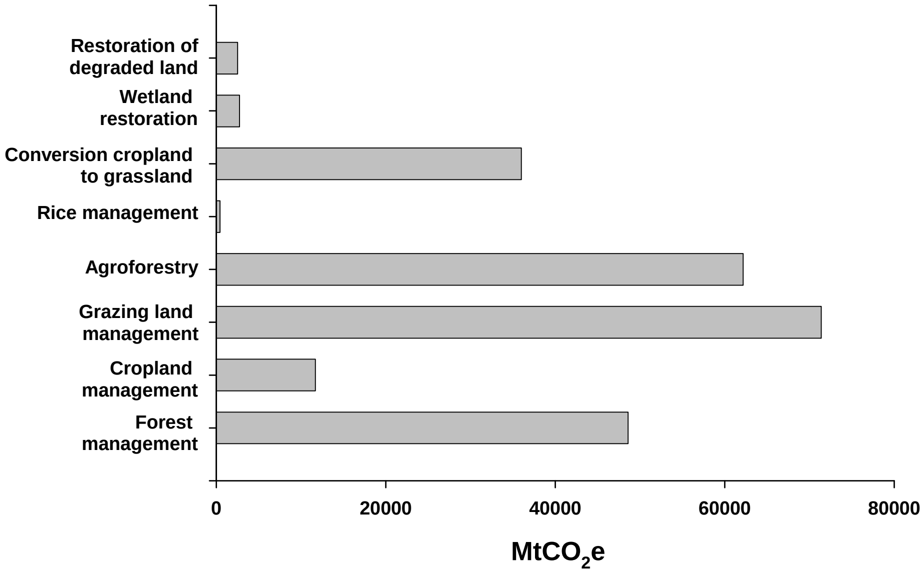

Figure 1. Technical potential for carbon sequestration of different land use and management options over a 30-year period (adapted from IPCC, 2000).

The IPCC scenario suggested that it would be possible, with considerable international effort, that 10% of the land available for improved pasture management could be under this improved management within 10 years and that as much as 20% could be under improved management within 40 years. Likewise, for agroforestry, the report suggested that 20% of the available land could be under this land management practice within 10 years and 40% within 40 years.

For this analysis, consider as an example a moderately intensive agroforestry system, which has been modelled using ENCOFOR (Environment and community based framework for designing afforestation, reforestation and revegetation projects in the CDM) decision support Carbon Model[3] (Figure 2). The system produces timber, with some food or cash crops grown in the understory. Examples of this system might be the rotational woodlots of Tanzania, the pine-coffee-banana systems of central Java, or the Eucalyptus and Poplar based agroforestry systems of the Indo-Gangetic Plain (Bekele-Tesemma, 2007).

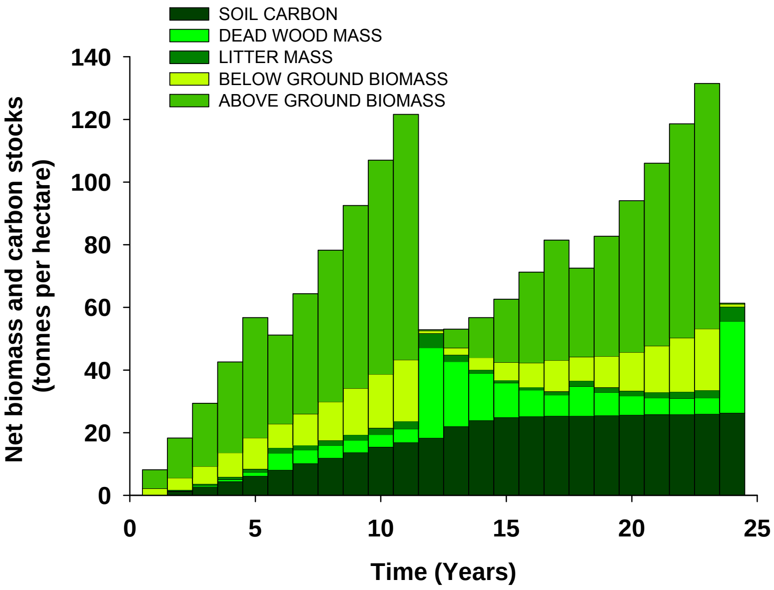

Figure 2. Projection of carbon accumulation in a multi-strata agroforestry system, generated using the ENCOFOR decision support Carbon Model[4].

In this system, the trees are harvested after 12 years and regenerated. The ENCOFOR model suggests that the average annual accumulation in this example over 30 years is 1.26 tonnes C per ha, and over 60 years this average figure drops to 0.52 tonnes per ha per year. The IPCC Special Report suggested an average carbon accumulation rate in an agroforestry system was about 3.1 tonnes per ha for a 30 to 50-year time horizon. These values are appropriate for a multi-strata system

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[3] Please see http://www.joanneum.at/encofor.

[4] Available at http://www.joanneum.at/encofor.

that is kept in place over a long period of time, such as the home garden systems of Africa or the jungle rubber agroforestry systems of Indonesia.

These two examples are used because they provide useful bounds to our calculations. In one case we have a system which is regularly harvested and therefore has lower annual accumulation rates because the aboveground biomass is regularly brought back to zero. In the other case, we have a permanent tree-based farming system.

Carbon sequestration potential can be calculated by taking the time frame proposed in the IPCC Special Report, taking the projections of area of land adopting the improved practices, and using both the IPCC and ENCOFOR projections for carbon accumulation rates, and the IPCC projection for grassland management. Table 3 presents the scenarios for agroforestry and grassland management. If we take the sum of the annual accumulation rates over the next 30 years, the results suggest that the total potential sequestration is on the order of 12 to 19 Gt of carbon or 45 to 70 Gt of CO_2e. This does not account for the carbon sequestered in harvested wood products from the agroforestry plantations.

Table 3. Estimates of C sequestration in agricultural lands for the two practices with the highest potential over 30 years. Two scenarios are presented for agroforestry, one based on the IPCC (2000) LULUCF report and one based on the projections of the ENCOFOR Carbon Model. The time period for the analysis is 30 years.

			Permanent agroforestry (IPCC)		Rotational agroforestry (ENCOFOR)	
Time (years)	Land area available (M ha)	Adoption/ conversion of area (%)	Rate of C gain (tC ha^{-1} y^{-1})	Carbon (Mt y^{-1})	Rate of C gain (tC ha^{-1} y^{-1})	Carbon (Mt y^{-1})
Agroforestry						
10	630	20	3.1	391	1.26	159
20		27		521		212
30		33		651		265
Grassland management						
10	3,400	10	0.7	238		
20		13		317		
30		17		397		

To begin to evaluate the investments required to achieve these levels of carbon sequestration, I will continue with the agroforestry example developed above. To calculate these costs, the ENCOFOR financial analysis tool was used and two rotations were analyzed. Costs of tree planting projects were calculated on a hectare basis and include those associated with plantation establishment (~US$ 780), maintenance costs like weeding and pruning (~US$ 440), costs for measurement and monitoring of the carbon sequestered (~US$ 190) and preparation of documentation for crediting carbon (~US$ 60). In many cases, extension and farmer education is required to teach farmers about new agroforestry systems. The total cost in this scenario is US$ 1470 per ha. From the example above, an agroforestry plantation contains an average 80 tonnes of biomass over its lifetime or 40 tonnes of C per ha in 5 carbon pools (aboveground biomass, belowground biomass, deadwood, litter, and soil carbon). The costs of establishment and maintenance of these plantations amounts to US$ 36.75 per tonne of carbon, or US$ 10.02 per tonne of CO_2e.

Not all of these costs need to be borne by the international community or by outside investors. Agroforestry systems are profitable in their own right. The example given here has a 22% internal rate of return. Agroforestry systems vary considerably across regions and have varying income generation potential. Costs can be shared with rural farmers who will benefit from these profitable systems. In most cases agroforestry systems are more profitable than subsistence agriculture. The idea of additionality in financing carbon sequestration is already embodied in the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol. Additionality is the criteria for carbon offset projects to determine offsets that occur in addition to business as usual. Additionality is determined by analyzing barriers.

There are numerous barriers to adopting improved agroforestry systems, including delayed returns on investment, lack of knowledge and labour shortages. In this case, we consider only the financial barrier due to negative cash flow over the first three years of the plantation. Investments of US$ 640 per ha would be required to overcome this and thus the cost of sequestering the carbon would be only US$ 16 per tonne of carbon or US$ 4.36 per tCO_2e. For the case of permanent agroforestry, assuming similar establishment and operating costs, the cost per tonne is around US$ 1.77 because of the higher productivity of the system.

Finally, to put this in a global perspective, the technical potential C sequestration of this scenario is 30.8 $GtCO_2$e for a total cost of US$ 134.4 billion. The actual potential suggested by the IPCC scenario is given in Table 4. Greater consideration of these land-use mitigation options is warranted, as these types of activities can offer multiple benefits. If well designed, agroforestry, grassland management, land rehabilitation, and wetland rehabilitation projects can contribute to biodiversity conservation, watershed protection, reduction of desertification, sustainable land management and poverty reduction (Verchot et al., 2007).

Table 4. Calculations of actual sequestration potential and costs for agroforestry using the IPCC (2000) scenario for adoption/conversion. Costs are calculated using total costs per hectare and the values suggested for investments aimed at removing barriers only.

		Sequestration potential		Implementation costs	
Time (years)	Adoption/ conversion of area (%)	Permanent agroforestry ($MtCO_2e\ y^{-1}$)	Rotational Agroforestry ($MtCO_2e\ y^{-1}$)	Full ($M)	Barriers only ($M)
10	20	1,434	583	5,843	2,544
15	23	1,672	682	6,836	2,976
20	27	1,910	777	7,791	3,392
25	30	2,149	876	8,783	3,824
30	33	2,387	972	9,739	4,240

Conclusion

There are many opportunities for mitigating non-CO_2 GHG and soil carbon emissions in agriculture. Emissions can be reduced by managing carbon and nitrogen more efficiently in agricultural ecosystems. There are opportunities for small emissions reductions at a net benefit or at zero cost, and these need to be pursued. There is potential for abatement of all sources, but with current technologies and the prevailing economic conditions these potentials are all low. The analysis presented here suggests that 11-13% of non-CO_2 GHG and soil carbon emissions could be abated at reasonable costs.

The analysis presented here shows that sequestration offers significant and cost-effective means of reducing atmospheric concentrations of GHGs. There are large potentials in a number of practices in agriculture. In the examples worked out in this report on agroforestry, total costs for sequestration were on the order of US$ 10 per tCO_2e and the estimates of global feasibility are between 0.7 and 2.1 $GtCO_2e$ per year. Many of these practices are economically beneficial, but do not occur due to a number of barriers. Investment targeted at overcoming these barriers is much less than the total cost, and therefore, there are opportunities to share costs with other beneficiaries. The analysis suggests that the cost associated with overcoming these barriers is less than US$ 4.50 per tCO_2e and perhaps as low as US$ 1.77 per tCO_2e.

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Can Iceland Become a Carbon Neutral Country by Reducing Emissions and Restoring Degraded Land?

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Introduction

Mitigation of human-induced changes to the earth´s climate is among the most pressing challenges of the next decades. Reducing emissions of greenhouse gases (GHG) and returning some of the CO_2 back into the earth for storage in soil and vegetation are both essential tools if countries are to become carbon neutral with regards to the GHG emissions.

Being carbon neutral refers to reducing one's own GHG emissions as far as possible and to offset the remaining emissions by other activities (see Figure 1). This concept is fairly new and refers to a voluntary action taken by countries, companies or individuals, without any legal requirements, setting emissions reduction targets well beyond targets set by international agreements such as the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol. Becoming carbon neutral is a new way of thinking. The Vatican is presently the only carbon neutral state; Costa Rica aims to reach this by 2030 and Norway by 2050 (Dobles, 2007; Norwegian Ministry of Finance, 2007; Planktos/KlimaFa, 2007).

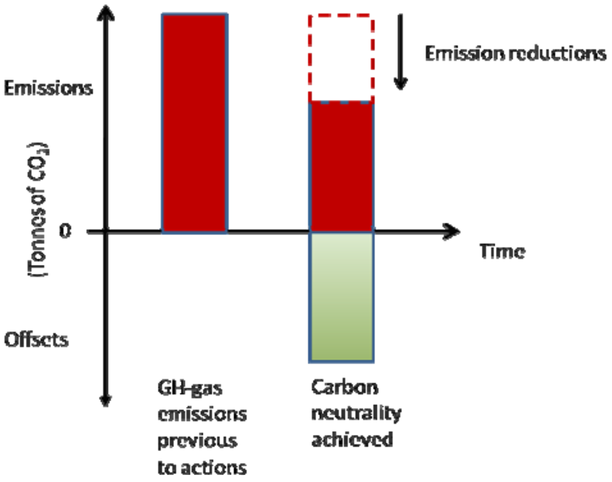

Figure 1. Carbon neutrality refers to reducing greenhouse gas emissions to the atmosphere as much as possible and to offsetting the remaining emissions by other activities (Ágústsdóttir, in press).

1. The Icelandic Profile

Iceland offers a good example of a country which could become carbon neutral within a few decades by combining emission reductions with mutually beneficial land restoration on vast areas in Iceland that have become degraded over the last millennium.

Iceland is responsible for about 0.01% of global greenhouse gas emissions, reflecting its small population of only about 300,000 people (UNFCCC, 2007). The country's emissions profile is unique in three ways: 1) the high proportion of renewable energy (70%) of the total amount of energy used; 2) emissions from the fishing fleet is about one-fourth of the total emissions; and 3) individual sources of industrial process emissions have a significant proportional impact at the national level due to the small size of the economy (Icelandic Ministry for the Environment, 2006).

The governmental climate strategy from 2007 contains the long-term goal of cutting net emissions in Iceland by 50-75% by 2050 (Icelandic Ministry for the Environment, 2007). That goal, or even more ambitiously, carbon neutrality, will only be reached with a concerted action from every sector. The Icelandic strategy contains rough estimates of emissions in 2005 of seven key sectors (Icelandic Ministry for the Environment, 2007): energy production (4% of total emissions); industrial processes (25%); the fishing fleet (19%); agriculture (13%); waste (5%); transport (20%); and industrial fossil fuel use (11%). The carbon-efficiency and mitigation potential of these sectors vary.

2. Emissions from Different Sectors

The potential for emission reduction varies greatly between the key emissions sectors in Iceland. Discussion on the three largest sectors follows below.

Transport is probably the least carbon-efficient sector in Iceland, and hence a priority for policy changes aimed at emission reductions. The potential for reducing emissions in this sector is seen as moderate in the short-term and significant in the long-term (UNFCCC, 2007). The state of transportation affairs cannot be considered climate friendly, according to a survey conducted in 2002 on transport in the Reykjavík capital area where 70% of the national population resides. At the time, private cars were used in 76% of all transport, walking/bicycling in 19%, and public transport in 4%. This leaves considerable potential for improvement, such as by increasing public transport and building a better network of bicycle and walking trails. The Ministry of Finance announced in September 2007 that it is revising the tax system on fuel and vehicles in order to promote the reduction in greenhouse gas emissions and the use of low-emission and alternative fuel vehicles (Icelandic Ministry of Finance, 2007b). The capital city of Reykjavík provides free parking spaces for certain defined clean or low-emission vehicles (Reykjavík City Council, 2007). Several towns in Iceland have offered free public transport (buses) to everyone, while others provide only high school and university students with this service, including the capital area (Reykjavík City Council, 2007). This has greatly increased the number of passengers using public transport. All of these initiatives are part of a progress towards a low-carbon society, but more changes are needed to reduce emissions in the transport sector, including changes on tax policies and economic incentives.

The fishing fleet in Iceland is responsible for about 19% of national emissions, reflecting the country's status as the 12th largest fishing nation in the world. Mitigation potential is seen as low in the short-term compared to that of other developed countries due to the fact that the Icelandic fishing industry is not subsidized, unlike those in many neighbouring countries (UNFCCC, 2007). Alternative fuels for ships may not be an option in the near future; however, there are possibilities of immediate emission reductions. Energy management systems can help minimize fuel consumption, and savings of up to 12% have been reported. More improvements are expected in the future (Marorka, 2007). Also, making shore-side power available to ships would limit the use of fossil fuels when in harbour, as electricity is produced by renewable energy in Iceland.

Industrial processes in Iceland are responsible for about 25% of national emissions, and the reduction potential is estimated to be low (UNFCCC, 2007). One example of possible reduction might be that fossil fuels used in the industrial production of fish meal could be replaced by electricity, reducing emissions from 122 Gg CO_2 (3.3% of total) to zero. In the aluminium industry, emissions of greenhouse gases per tonne of produced aluminium have been reduced by more than two-thirds since 1990, and are currently only about 35% of the global average, counting both energy- and process-related emissions. The potential for further reduction is therefore seen as low, as this industry in Iceland is possibly the most carbon-efficient in the world. New technologies that are being studied, like carbon-free anodes in aluminium production, could significantly reduce emissions in the future, but are not feasible at present (UNFCCC, 2007). Despite a highly carbon-efficient aluminum industry, emissions from it are expected to increase in the future as further growth of this sector in Iceland is expected due to plentiful and low-cost energy.

3. The Potential for Sequestration

In addition to reducing emissions in Iceland, there is a large potential for sequestering carbon into soil and vegetation. Iceland provides a good example of the multiple roles of carbon sequestration in reaching important environmental, social and economic goals (Arnalds, 2004; Ágústsdóttir, in press). Revegetation is defined in the Kyoto Protocol as a direct human-induced activity initiated after 1990 to increase carbon stocks on sites through the establishment of vegetation that covers a minimum area of 0.05 ha but does not meet the UNFCCC definitions of afforestation and reforestation. Revegetation is largely regarded as a win-win strategy, restoring soil fertility and land quality, strengthening ecosystem services, conserving and restoring biological diversity, increasing food security and mitigating climate change. Revegetation in Iceland refers to reclaiming vegetation on barren or severely damaged land that needs external or human input to overcome ecological thresholds. The goal is to recreate an ecosystem that will naturally regenerate in the future.

The potential of the soils in Iceland for carbon sequestration is high because of its unique composition. Icelandic soils are exclusively from two soil orders, Andosols (54%) and Histosols (6.7%) (Arnalds and Grétarsson, 2001). Of all soil orders, these two store the most C per unit area, with mean global values of 31 and 218 kg m^{-2} for Andosols and Histosols, respectively (Batjes, 1996). The difference between soils of barren areas, with <1 kg C m^{-2} and fully vegetated undisturbed Andosols with >40 kg C m^{-2}, indicates that reclamation of degraded sites may have a high potential for carbon sequestration, which may last for a long time until the system reaches a saturated carbon balance (Arnalds et al., 2000).

The carbon sequestration potential on a national scale is demonstrated by the enormous soil erosion Iceland has suffered since the time of its settlement. Areas with considerable to extremely severe erosion cover about 40% of the country (Arnalds et al., 2001). In an assessment of barren lands in Iceland, Óskarsson et al. (2004) estimated that between 120 and 500 million tonnes of organic carbon has been lost from Icelandic soils during eleven centuries of human settlement, approximately half of which have been oxidized and lost to the atmosphere. Accounting for degradation of soil and vegetation outside the assessed areas, the total carbon losses rest higher.

In 2005, carbon sequestration due to revegetation amounted to 533 Gg CO_2 or 14.4% of total emissions excluding LULUCF, or 9.7% of total emissions including LULUCF (Hallsdóttir et al., 2007). These carbon offsets can be increased significantly, as there is an urgent need to return some of the lost carbon back to the land, recharging the ecosystems. With the current rate of revegetation projects initiated since 1990, carbon sequestration could easily reach 1000 Gg CO_2 in 2020. The potential is however much greater since such large areas of the country are suffering from severe erosion and poor land health. A combination of revegetation, afforestation and wetland restoration as climate change mitigation activities could provide important leverage for Iceland's GHG budget.

Carbon sequestration is a method of emissions reduction that is immediately available using technology developed by nature itself. Early action increases the likelihood of avoiding the most severe consequences of global climate change according to the findings of the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report: Climate Change Mitigation (IPCC, 2007). No one method of emissions reduction will be a sole solution for climate mitigation. The use of various options in different sectors is needed in a concerted action to achieve this aim, and carbon sequestration can be one important means to that end.

Although carbon sequestration by revegetation and reducing emissions are two different routes to the same goal, many environmental groups see this as an escape route for countries to reduce emissions. Therefore, the overall quality and benefits of such projects must be mutually supportive to the overall goals of the Multilateral Environmental Agreements, and with an emphasis on verifiability and permanency of the carbon sequestered.

4. Examples of Activities Resulting in Carbon Storage in Iceland

Financing revegetation is relatively cheap compared to other more expensive, experimental, high-technology projects for removing carbon from the atmosphere. Financial assistance, incentives and disincentives are important for stimulating land improvement. What follows is a description of some of the practices currently in use or possibilities that could be employed regarding increasing carbon sequestration in soil and vegetation in Iceland.

Regulation on land use: It is important to increase sustainability of land use on both common and private lands in Iceland. This would aid in both preventing further carbon losses through land degradation and in stimulating carbon storage through recovery of vegetation and soils. In the year 2000, the Icelandic government and sheep farmers signed a contract on agricultural support which has partial cross-compliance, i.e. about one-third of the support is dependent on the quality of land use. The subsidy agreement was then revised and renewed in 2007. Participation is on a voluntary basis, but farmers that meet the quality criteria receive up to 22.5% more subsidies in government support. The main criteria on the use of land for grazing is that the condition of the land shall be acceptable, and the state of vegetation stable or improving. Farmers not meeting the criteria have to submit land quality improvement plans. This cross-compliance scheme is resulting in both avoidance of carbon losses from land degradation, and a direct increase in carbon sequestration.

Farmers Heal the Land Programme: Within this incentives programme for better land health that has been operating since 1990, the Soil Conservation Service of Iceland (SCS) now assists about 20% of Icelandic farmers to revegetate degraded land, to halt erosion, and to reclaim land for grazing and other agricultural purposes. The SCS provides consultation and seeds (if needed) and partially refunds the cost of fertilizer; farmers take care of seeding, fertilizing and transport costs.

Land Improvement Fund (‘Landbótasjóður’): This is another example of a programme aimed at improving better land health which also leads to increased carbon sequestration. It was established in 2003 with the purpose of moving responsibility, initiative and execution of soil conservation projects to local authorities, land owners, local governments, communities and non-governmental organizations by providing funding for soil conservation and land restoration projects that might not be applicable to the framework of the Farmers Heal the Land Programme. The SCS provides consultation, funding and supervision of projects. Projects that conform to the aims and focal points of long-term soil conservation strategy planning for 2003-2014 are given priority.

Afforestation: Afforestation of treeless landscapes results in a net carbon sequestration in biomass (e.g. IPCC, 2000; Snorrason et al., 2002). The woodland cover in Iceland in 1990 was 1% of land area (Icelandic Ministry for the Environment and Icelandic Institute of Natural History, 2001). In 2005, sequestration due to forest amounted to 126.27 Gg CO_2, or 3.4% of total emissions that year (Hallsdóttir et al., 2007).

There are plans for increasing forest cover and associated carbon sequestration considerably. In the most recent forestry-related legislation, the future goal is set to increase woodland and forest cover to at least 5% of the lowland surface area below the altitude of 400 m during the next 40 years (Althingi, 2006). This 5% goal is expected to reach a maximum sequestration of 1.3 million tonnes CO_2 yr^{-1} (or 1300 Gg CO_2 yr^{-1}) in 2040 (Snorrason, 2006).

Restoration of wetlands: Extensive drainage of wetlands occurred in Iceland in the period 1945-1990, due to subsidy programmes by the government. During this period, approximately 4,500 km^2 (60-75%) of all lowland wetland areas were drained for cultivation purposes (Icelandic Ministry for the Environment and The Icelandic Institute of Natural History, 2001; Óskarsson, 1998). In the lowlands, only a few areas remain intact.

Research has shown that reclaimed wetlands can sequester carbon, while drained wetlands are big emitters of CO_2 (Icelandic Ministry for the Environment, 2006). These drained wetlands currently emit about 1.8 million tonnes CO_2 per year (or 1800 Gg CO_2 yr^{-1}, calculated using UNFCCC default emission factors (IPCC, 2003)). A typical undisturbed wetland in Iceland sequesters about 51-99 tonnes CO_2 per km^2 yr^{-1} (H. Óskarsson 2007, personal communication).

Conditions for wetland restoration in Iceland are considered favourable as most of the drained wetlands have not been intensively cultivated or excavated. They still have semi-natural vegetation that is relatively rich in wetland species. In most cases, establishment of suitable hydrological conditions should be sufficient for the restoration of mires and other wetland areas (Icelandic Ministry of Agriculture, 2006). Today, only about one-eighth of drained wetlands are currently being used as agricultural land, mainly as hayfield and pasture, leaving much room for wetland restoration (H. Óskarsson 2007, personal communication). If only half of the drained wetlands were to be restored, then their present carbon budget emission of 0.9 million tonnes CO_2 yr^{-1} could be turned into sequestration of approximately 0.12-0.22 million tonnes CO_2 yr^{-1} (or 120-220 Gg CO_2 yr^{-1}).

Restoration of wetlands is a priority area of the government's long-term climate mitigation planning (Icelandic Ministry for the Environment, 2002, 2007), but an action plan and funding have not been developed.

Other voluntary carbon offsets: Many individuals and companies are willing to volunteer funding, either due to their climatic conscience or for the purpose of presenting a good corporate responsibility related to environmental concern. 'Kolviður', The Iceland Carbon Fund, was founded by the Icelandic Forestry Association and the Icelandic Environment Association and is sponsored by the Government of Iceland, Reykjavík Energy and Kaupthing Bank. It is a carbon offsetting company that facilitates carbon sequestration through afforestation. This effort has definitely put carbon offsets on the map in Icelandic society. Projects on a national offset scale need organization, careful species selection and the consideration of multiple benefits for society.

Carbon sequestration with geological processes: In addition to reducing emissions into the atmosphere and sequestering carbon in soil and vegetation there is the possibility of sequestering carbon with geological processes or chemical weathering. One environmental impact of geothermal production is the emission of gases, such as CO_2, into the atmosphere. Wells already drilled for the reinjection of liquid have been made available by Reykjavík Energy at Hellisheiði in Iceland for mineral sequestration studies in an attempt to devise new ways of disposing of CO_2. A possible means of storing CO_2 underground is to use chemical bonding of injected CO_2 in a mineral phase. Igneous rocks such as basalt provide the medium to effect the precipitation of carbonate minerals from injected CO_2-saturated fluids (Matter et al., 2007). Upon injection into basalt aquifers, CO_2 will acidify the groundwater and the acid will be neutralized by water-rock reactions. Results of these studies will hopefully provide means of disposal of CO_2 by sequestration in basalts.

5. Can Carbon Neutrality Be Achieved?

The global process of climate change will influence ecological, economic and social activities and development at the regional and local level in all countries, making it one of the more profound challenges to sustainable development and poverty eradication.

Whether the goal of carbon neutrality will be achieved depends very much on the current and future political and financial environment. Generally, the political horizon (months to years) is quite short compared to that for climate issues (years to decades), which, again, affect decision patterns on policy issues. Politics are very much influenced by societal views and pressures when acting upon climate mitigation. In recent years, climate issues have gained higher visibility at the international and national scales. Increased pressure is coming from the public, NGOs and other vested interest groups, along with peer pressure within sectors and between companies. This increased interest in climate mitigation may affect the priority placed on environmental/climate issues in national politics and subsequently affects available funds for mitigation actions.

The legal basis and requirements for emissions reduction in Iceland is currently weak. No laws or regulations cover the commerce of carbon credits and thus no national carbon market is in place. Presently, this prevents land users and large-scale emitters from cooperating towards lowering emissions of greenhouse gases through carbon sequestration, and therefore needs to be remedied.

With its renewable energy resources, actively employing new climate-friendly technology, the vast potential for carbon sequestration by the restoration of degraded land, restoration of wetlands, forestry and more sustainable use of land, Iceland may have the option of becoming a carbon neutral country much sooner than anticipated in the current governmental strategy.

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