

# Food Security and Agricultural Mitigation in Developing Countries: Options for Capturing Synergies



Food and Agriculture  
Organization of the  
United Nations



# Food Security and Agricultural Mitigation in Developing Countries: Options for Capturing Synergies

October 2009



Food and Agriculture  
Organization of the  
United Nations

The conclusions given in this report are considered appropriate for the time of its preparation. They may be modified in the light of further knowledge gained at subsequent stages. The designations employed and the presentation of material in this information product do not imply the expression of any opinion whatsoever on the part of the Food and Agriculture Organization of the United Nations (FAO) concerning the legal or development status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

The mention of specific companies or products of manufacturers, whether or not these have been patented, does not imply that these have been endorsed or recommended by FAO in preference to others of a similar nature that are not mentioned.

All rights reserved. Reproduction and dissemination of material in this information product for educational or other non-commercial purposes are authorized without any prior written permission from the copyright holders provided the source is fully acknowledged.

Reproduction of material in this information product for resale or other commercial purposes is prohibited without written permission of the copyright holders.

Applications for such permission should be addressed to:

Chief

Electronic Publishing Policy and Support Branch

Communication Division

FAO

Viale delle Terme di Caracalla, 00153 Rome, Italy

or by e-mail to:

[copyright@fao.org](mailto:copyright@fao.org)

# Table of contents

Foreword	5
Acknowledgments	6
Acronyms and abbreviations	7
Executive summary	8
<b>1 Introduction</b>	<b>10</b>
1.1 The context	10
1.2 The paper	12
<b>2 Synergies and trade-offs between agriculture mitigation and food security</b>	<b>13</b>
2.1 Current state of food security	13
2.2 Global food needs to 2050	14
2.3 Changes in agricultural practices and their impacts on adaptation/food security	17
2.4 Agricultural mitigation options	20
2.5 Costs	22
2.6 Mitigation and food security: where and how can synergies be realized?	24
<b>3 Enabling action on food security and climate change mitigation: financing options</b>	<b>26</b>
3.1 Agricultural investment requirements vis-à-vis climate financing	26
3.2 MRV requirements for different financing options	29
3.2.1 National GHG inventory	29
3.2.2 MRV for NAMAs	31
3.2.3 MRV for crediting and trading approaches	31
3.2.4 MRV for support	32
3.3 Economics of MRV	33
3.4 Conclusions	34
<b>4 Moving from negotiations to implementation: options for action</b>	<b>35</b>
4.1 Anchoring agricultural mitigation at the international level	35
4.1.1 High level political commitment	35
4.1.2 Building international confidence in agricultural mitigation	35
4.1.3 Establishing an international network of agricultural carbon pilots	36
4.1.4 Securing long-term financing and partnerships: in search of the champions	36
4.2 Anchoring agricultural mitigation at the country level	36
4.2.1 Ensuring nationally appropriate action	36
4.2.2 Prioritizing agricultural mitigation actions	37
4.2.3 Assessing potential institutions for a carbon value chain	39
4.2.4 Making the link to smallholders-what is needed?	39
4.2.5 Building confidence and readiness for implementation	40
4.3 Measuring, Reporting and Verification (MRV) requirements – part of a step-wise approach	41
4.4 Conclusions	41

5	Conclusions and recommendations	42
6	References	45
7	Annexes 51	
7.1	Synergies and trade-offs between agricultural mitigation and food security	52
7.2	Measuring, Reporting and Verification (MRV) requirements for agricultural mitigation	56
7.3	Ex-Ante Tool to assess mitigation benefits of investment projects	69
7.4	External implications of domestic agricultural mitigation policy	72
7.5	FAO sources of data relevant for measuring, reporting and verification (MRV) of agricultural mitigation	74
7.6	Use of spatially referenced tools to map the opportunities for mitigation: a FAO example from The State of Food and Agriculture (SOFA)	75
7.7	Technical background paper on Nationally Appropriate Mitigation Actions (NAMAs) for developing countries in the context of agricultural land management	77

## Foreword

Years of work in farmers' fields by the FAO, other technical organizations, and national and international research institutes, have generated a sound knowledge base on practices, techniques and technologies for improving farming systems in a way that supports food security and development. The changes that farmers could make to improve crop and livestock production, can also generate another type of product—emission reductions and removals. Increasing carbon sequestration in agricultural systems by restoring, protecting and conserving soils can generate a significant share of total emission reductions required in the next few decades to avoid catastrophic levels of climate change. Increasing soil carbon sequestration also increases soil organic matter, which is fundamental to improving the productivity and resilience of cropping and livestock production systems.

Such clear examples of “win-win” opportunities for development and environment would seem natural candidates for prioritization and widespread implementation. However there are significant financial, institutional and political challenges to achieving the needed transformation of farming systems. First and foremost, a shift to a more holistic view of climate change and agricultural development is needed that includes recognition of the range of demands put on the sector, as well as the range of benefits it can provide. Important progress on this has recently been made within the Declaration of the World Food Summit on Food Security (Rome, 16-18 November 2009), which explicitly recognized the link between mitigation, adaptation and food security, and affirmed commitments to supporting adaptation and mitigation in agriculture while ensuring food security. Another important step will be to harness financing for mitigation to support changes in smallholder farming systems that produce synergies between food security, adaptation and mitigation. This could be enabled by the outcome of COP 15 in Copenhagen, as well as subsequent work under the UNFCCC.

Ongoing technical work to support the identification, financing and implementation of synergistic strategies and action in smallholder agricultural systems will also be essential. Work across FAO departments is already supporting this process and this will continue, with integration of work on agricultural production, food security, and adaptation and mitigation of climate change. This report is the result of interdepartmental collaboration between the Natural Resources Management and Environment Department and the Economic and Social Development Departments of the FAO, drawing upon work from inside and outside the Organization. An initial draft was presented at the Barcelona climate change talks in November 2009. The final revised version incorporates some additional text prompted by comments on the draft version. The report is intended to be an initial stimulus to a process of discussion, and ultimately commitment to support reforms in smallholder agricultural systems that improve food security, as well as climate change adaptation and mitigation.

**Peter Holmgren,**  
Director Environment, Climate Change  
and Bioenergy Division  
Natural Resources Management and  
Environment Department

**Kostas Stamoulis,**  
Director, Agricultural Development  
Economics Division  
Economic and Social Development  
Department

## Acknowledgements

This paper is the outcome of a collaborative effort between the Natural Resources Management and Environment Department and the Economic and Social Development Department of the Food and Agriculture Organization of the United Nations (FAO). The authors include Wendy Mann, Leslie Lipper, Timm Tennigkeit, Nancy McCarthy and Giacomo Branca of the FAO. Keith Paustian of Colorado State University prepared material for Annex 7.2 on MRV approaches for agricultural mitigation.

FAO gratefully acknowledges the following colleagues who have contributed their knowledge to the content of this paper: Ralph Ashton (Terrestrial Carbon Group), Martial Bernoux (IIRD), José Manuel Bulas Montoro (Mexican Senate), Bernard Giraud (Danone), Keith Paustian (Colorado State University), Pete Smith (University of Aberdeen), Johannes Woelcke (World Bank), Andreas Wilkes (ICRAF) and David Zilberman (University of California Berkeley). This paper has also benefited from the active support of colleagues within FAO who also gave valuable contributions: Blanca Amado, Louis Bockel, Jelle Bruinsma, David Colbert, Cesar Falconi, Theodor Friedrich, Josef Schmidhuber, Christina Seeberg-Elverfeldt and Keith Wiebe.

FAO is most grateful to the Australian Government for financial support provided towards the preparation, editing and printing of this publication.

## List of acronyms

AAUs	assigned amount units
AFOLU	agriculture, forestry and other land use
BAP	Bali Action Plan
BAU	business as usual
C	Carbon
CDM	Clean Development Mechanism
CH <sub>4</sub>	Methane
CO <sub>2</sub>	Carbon Dioxide
CO <sub>2e</sub>	Carbon Dioxide equivalent
COP	Conference of the Parties
CSO	civil society organization
ERs	emission reductions
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GEF	Global Environment Facility
GHG	green-house gas
kcal	kilocalories
IFAD	International Fund for Agricultural Development
IPCC	Intergovernmental Panel on Climate Change
LCA	life cycle analysis
LDCs	least developed countries
LULUCF	land use, land-use change and forestry
MDGs	Millennium Development Goals
MRV	measurement, reporting and verification
N	Nitrogen
N <sub>2</sub> O	Nitrous Oxide
NAMA	nationally appropriate mitigation action
NGO	non-governmental organization
OECD-DAC	Development Assistance Committee of the Organisation for Economic Co-operation and Development
ODA	official development assistance
PAMs	Policies and Measures
PoA	programme of activities
REDD	Reduction of Emissions from Deforestation and forest Degradation
R&D	research and development
SALM	sustainable agricultural land management
SBSTA	Subsidiary Body on Scientific, Technical and Technological Advice
SDPAMs	sustainable development policies and measures
SNLT	sector no-lose target
tCERs	temporary certified emission reductions
UNFCCC	UN Framework Convention on Climate Change
VCS	Voluntary Carbon Standard

## Executive summary

Two key challenges facing humanity today stem from changes within global food and climate systems. The 2008 food price crisis and global warming have brought food security and climate change to the top of the international agenda. Agriculture plays a significant role in both and these two challenges must be addressed together, rather than in isolation from each other.

Farmers will need to feed a projected population of 9.1 billion in 2050. Meeting this demand together with challenges from climate change, bioenergy and land degradation puts enormous pressure on the agricultural sector to provide food, feed and fibre as well as income, employment and other essential ecosystem services. Making changes to agricultural production systems, particularly amongst smallholders, is a key means of meeting this objective. Such changes also have implications for adaptation and mitigation in the agricultural sector.

The paper explores potential synergies between food security, adaptation and climate change mitigation from land-based agricultural practices in developing countries, which could help to generate the multiple benefits needed to address the multiple demands placed on agriculture. It indicates promising mitigation options with synergies, options that involve trade-offs, possible options for required financing, and possible elements in designing country implementation processes.

Key conclusions of the paper include:

- A more holistic vision of food security, agricultural mitigation, adaptation and development is needed if synergies are to be maximized and trade-offs minimized. This needs to be mainstreamed into global agendas and national strategies for addressing climate change and food security.
- Realizing the synergies and minimizing trade-offs between agricultural mitigation and food security will require financing for up-front investments, opportunity costs and capacity building. Current levels of agricultural investment are inadequate to meet these and other costs.
- The magnitude of potential financing for land-based mitigation, relative to overall investment requirements for agriculture, indicate that leveraging mitigation finance to support climate smart agricultural development strategies and investments will be necessary to capture synergies between mitigation, adaptation and food security.
- There is currently no consensus on measuring, reporting and verification (MRV) for financing mechanisms, but decisions in this regard would affect the costs and viability of different agricultural mitigation activities.

---

The main recommendations of the paper are:

- (1) Capturing synergies and managing trade-offs between food security and agricultural mitigation can be part of the solution to these two challenges and this should be reflected in the outcome reached at the United Nations Climate Change Convention (UNFCCC) Conference of the Parties (COP15) in Copenhagen.
  - (2) The formulation and implementation of climate change and food security strategies will benefit from greater awareness of the potential synergies and trade-offs between these two policy areas within the agriculture sector, and how they might be best managed to generate multiple benefits rather than perverse outcomes.
  - (3) Capturing the potential of agricultural mitigation and its co-benefits will require new and additional resources, multiple funding streams, innovative and flexible forms of financing, and the unequivocal eligibility of agriculture, including soil carbon sequestration, in existing and any new financing mechanisms.
  - (4) Beyond Copenhagen, possible next steps that Parties may wish to consider, include:
    - (i) A work programme on agriculture initiated within the UNFCCC Subsidiary Body for Scientific and Technological Advice (SBSTA), with technical support provided, inter alia, through already ongoing Intergovernmental Panel on Climate Change (IPCC) - FAO cooperation. Such a work programme could address methodological issues, including those related to reference levels, financing, and MRV. A decision in this regard could be taken by the UNFCCC COP, at its fifteenth session in Copenhagen.
    - (ii) A suite of country-led pilots launched to build readiness, confidence and capacity for implementation of nationally appropriate agricultural mitigation action. The modality of implementation could be a phased approach, linked to country-specific capacities, circumstances and sustainable development processes.
-

# 1

## Introduction

### 1.1 The context

Two key challenges currently facing humanity stem from changes occurring within global food and climate systems. The food price crisis of 2008 and already discernable signs of global warming, which are thought to be symptomatic of deeper and longer term changes, have brought food security and climate change to the apex of the international agenda. Agriculture has significant roles in both, underlining the need to address the two challenges together, rather than in isolation from each other.

Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC) states that the ultimate objective of the Convention is:

“...stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.”

It is widely held that achievement of this objective will entail: 1) more ambitious commitments by developed countries to reduce emissions; and 2) internationally supported nationally appropriate mitigation action by developing countries. In line with the Convention, both should be done in ways that 1) do not negatively affect development processes; 2) adhere to the parameters outlined in Article 2 above and 3) respect common but differentiated responsibilities and capabilities. Decisions to be taken by Parties, currently negotiating a Copenhagen outcome, are to shape how such commitments might be pursued and such action implemented and supported.

The objectives of this paper are to provide information on the potential of agricultural systems to contribute to meeting the ultimate objective of the Convention and to identify options for enabling this contribution.

Agriculture is the major economic sector of many developing countries and most Least Developed Countries (LDCs). It is the main livelihood of 75 percent of the poor in developing countries. Farmers constitute the largest group of natural resource managers on earth (land, water, domesticated genetic resources). Agriculture is expected to feed a population that will number 9.1 billion in 2050, while providing income, employment and environmental services. Responding to more rapid and intense climate changes is additional to these other demands on the sector and follows decades of declining investment in the sector and a global financial crisis.

At the same time, agriculture is an important source of greenhouse gas (GHG) emissions, representing 14 percent of the global total. Developing countries are the source of 74 percent of these emissions (Smith et al. 2008). If related land-use change, including deforestation (for which agriculture is a key driver) and emissions beyond the farmgate are considered, the sector's share would be higher. However, the technical mitigation potential of agriculture is high and 70 percent of this potential could be realized in developing countries.

Agricultural systems can contribute significantly to overall mitigation that will help to reduce the extent of adaptation required and catastrophic impacts on systems and sectors, on which lives and livelihoods depend. Agricultural systems will also need to adapt to unavoidable climate change impacts in order to ensure food security and sustainable development. Most developing countries will need to do both and will need to involve smallholders.

Many agricultural mitigation options, particularly those that involve soil carbon (C) sequestration (which is 89 percent of the technical mitigation potential of agriculture), also benefit adaptation, food security and development, referred to as co-benefits. These options involve increasing the levels of soil organic matter, of which carbon is the main component. This would translate into better plant nutrient content, increased water retention capacity and better structure, eventually leading to higher yields and greater resilience. These agricultural mitigation options can be pursued in the context of, and without adverse affects to, national sustainable development processes. They can also contribute to implementation of Article 2 of the Convention.

However, some of these options involve difficult trade-offs, with benefits for mitigation but negative consequences for food security and/or development. For example, biofuel production provides a clean alternative to fossil fuel but can displace or compete for land and water resources needed for food production. Restoration of organic soils enables greater sequestration of carbon in soil, but may reduce the amount of land available for food production. Restoration of rangelands may improve carbon sequestration but involves short-term reductions in herder incomes by limiting the number of livestock. Some trade-offs can be managed through measures to increase efficiency or through payment of incentives/compensation. Other options may benefit food security or agricultural development but not mitigation.

The imperative to increase sustainably the productivity and resilience of agricultural production systems, while contributing to emission reductions, follows decades of declining investment in the sector and a global financial crisis. New and additional resources will be needed to cover additional requirements, such as: formulation/implementation of national agricultural mitigation strategies, incentives for adoption of mitigation options by rural producers, and readiness/confidence/capacity building, including the use of technologies and methodologies for MRV of both action and support. More innovative financing will also be required, drawing on multiple funding streams, integrating new mitigation financing with existing official development assistance (ODA) and utilizing a range of financing mechanisms from public sector funds to market-based mechanisms. Above all, financing mechanisms, will need to be inclusive of, and appropriate to, the specificities of agriculture. This applies to both newly created financial mechanisms or reformed existing ones, and the two are not mutually exclusive.

While the profile of agriculture within the climate change negotiations has improved, it is still considered to be a difficult sector. Two steps could help to bring agriculture into the mainstream of mitigation action. First, a work programme on agriculture could be placed within the UNFCCC SBSTA. Such a work programme could address methodological issues related to reference levels, financing, and MRV. Second, a suite of country-led pilots could be considered to build readiness for implementation through a phased approach linked to country capacities and circumstances.

## 1.2 The paper

This paper is situated between two important international gatherings on the twin challenges of food security and climate change: the World Summit on Food Security (Rome, November 2009) and the UNFCCC COP 15 (Copenhagen, December 2009). Parties at the World Summit signed a Declaration recognizing the links between mitigation, adaptation and food security, and affirming the parties' commitments to supporting adaptation and mitigation actions while ensuring food security. Building on this momentum towards an agreement in Copenhagen, this paper explores options for enabling mitigation actions in the agricultural sectors of developing countries by exploring the potential to realize synergies with food security and adaptation and by considering relevant financing options and their MRV requirements. The paper concludes with possible next steps to be taken at the international and national levels to ensure that synergistic mitigation opportunities in developing country agricultural sectors are realized.

# Synergies and trade-offs between agriculture mitigation and food security

# 2

Meeting the food demands of a global population expected to increase to 9.1 billion by 2050, and improving incomes and livelihoods to enable access to food, will require major improvements in agricultural production systems. At the same time, agricultural mitigation has the potential to enhance removals and reduce emissions. The questions addressed in this chapter are 1) the extent to which there are potential synergies or trade-offs in the changes in production needed to meet global food security objectives and those needed to increase land-based mitigation from the agricultural sector; and 2) identifying means of enabling actions that contribute to both objectives.

## 2.1 Current state of food security

The World Food Summit in 1996 adopted the following definition of food security: “Food security exists when all people at all times have physical or economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life” (FAO 1996). FAO’s State of Food Insecurity report (2002) refers to four elements of food security: food availability, food accessibility, food utilization and food system stability. Availability focuses on food production whereas accessibility focuses on the ability of people to obtain food, either through production, purchase or transfers. Food utilization focuses on the nutritional value of food, the interaction with physiological condition and food safety. Food system stability focuses on stability of supply and access, as well as the ability to respond to food emergencies.

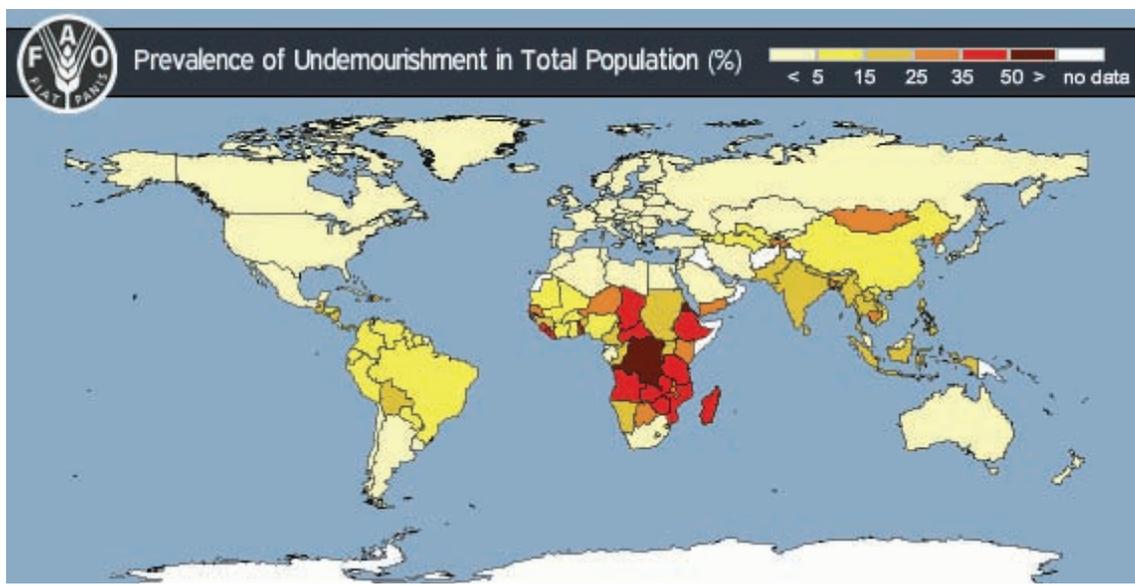
As captured in the 2008 State of Food Insecurity report, there are nearly one billion people who are undernourished. As shown in figure 2.1, the overall proportion of the population suffering from undernourishment in sub-Saharan Africa remains persistently high at 30 percent, and is over 50 percent in some countries. Undernourishment also affects more than a fifth of the population of South Asia (21%), and many Caribbean countries (23%) (FAO 2008b).

Food accessibility for many people in the developing countries remains closely tied to local food production (FAO 2008a,b; Bruinsma 2009). The World Development Report 2008 stresses the importance of agriculture-led growth to increase incomes and reduce poverty and food insecurity in the least developed and developing countries. Countries with large food insecure populations are often also those whose agricultural systems are highly vulnerable to climate shocks now, particularly in sub-Saharan Africa and South and Southeast Asia (Gregory et al. 2005).<sup>1</sup> Given the close link between local production and food insecurity, investments in the agricultural sector that increase food availability and strengthen the resilience of the food production system will have immediate positive impacts on all elements of food security in food insecure regions.

---

<sup>1</sup> As noted by many authors, global food production is sufficient, at the moment, to cover global consumption needs (c.f. FAO, 2008b). However, trade in agricultural products is still quite low, at approximately 16% (FAO, 2008a), so that national consumption remains closely – though not perfectly – linked to national production. It is important to note that accessibility by the poor at the local level largely depends on income, and incomes are affected by more than simply agricultural output.

Figure 2.1: FAO World Hunger Map



## 2.2 Global food needs to 2050

Although the rate of global population growth is declining, the UN projects that total population will increase by more than 30 percent by 2050 (UN 2009), i.e. from the current 6 billion to approximately 9.1 billion in 2050. Most of the increase is projected to occur in South Asia and sub-Saharan Africa. Both regions have a large share of the world's food insecure population, dependent on agriculture for their livelihoods.

FAO projects that global agricultural production will need to grow by 70 percent overall by 2050 (Bruinsma 2009). These projections are based on assumptions about population and income growth as well as dietary patterns. Under the baseline scenario<sup>2</sup>, per capita calorie availability is projected to increase 11 percent by 2050, to an average of 3130 kcal/per capita. Under this scenario, 4 percent of the developing world population would still be food insecure.<sup>3</sup>

There are three main means of increasing agricultural production to meet projected increases in demands: 1) bringing new land into agricultural production; 2) increasing the cropping intensity on existing agricultural lands; and 3) increasing yields on existing agricultural lands. Adoption of any one of these strategies will depend upon local availability of land and water resources, agro-ecological conditions and technologies used for crop production, as well as infrastructural and institutional development.

Using the FAO 2006 baseline demand projections, Bruinsma (2009) calculates the potential sources of agricultural supply response by region and for the main categories of production. The analysis, however, excludes any explicit impacts of climate change on agricultural production and assumes that land for biofuels produced domestically remains at 2008 levels<sup>4</sup>. The study assumes that the bulk of foods consumed will be produced locally, based on the observation that only 16 percent of world

<sup>2</sup> Described in FAO 2006.

<sup>3</sup> This result is based upon an assumption of shifts in dietary patterns involving an increase in the share of high value foods and meat consumed as incomes rise. Lower calorie content and inefficiency associated with conversion of feed grains to meat calories translates into reduced increases in caloric availability per increase of agricultural production. Actual experience with income growth and dietary transformation could vary from this projection, which would in turn affect the needed supply response from agriculture – however in this report we will use this as the base case.

production enters international trade at present. Given these assumptions, a detailed investigation was conducted of present and future land/yield combinations for 34 crops under rainfed and irrigated conditions in 108 countries and country groups. This analysis yields a baseline projection of potential sources of agricultural production growth by region for the three main categories of supply response as shown in table 2.1.

Seventy-five percent of the projected growth in crop production in developing countries comes from yield growth and 16 percent from increases in cropping intensity. Arable land expansion is found to be an important source of growth in sub-Saharan African and Latin America. These results highlight the potential tensions that may be created between the need to increase food production and the possible transition towards sustainable, low emission agriculture strategies if viable opportunities are not developed to enable meeting both goals.

Despite several caveats associated with these assessments, the analysis is a useful point of departure for understanding the scope and magnitude of changes needed in agricultural production systems<sup>5</sup>. It can be expanded to include information from other studies on factors that could change the nature of the agricultural supply response. While there are many factors, three are particularly important: potential impacts of climate change on agricultural production, the effects of environmental degradation, and the potential effects of future biofuel development.

Climate change can impact agricultural production and supply response via changes in temperature and precipitation that in turn affects which crops can be grown and when, as well as potential yields. Several studies conclude that in the near term (e.g. to 2050) relatively limited changes in temperatures and precipitation are expected to limit negative impacts on global agricultural production (Fischer et al. 2007; Schmidhuber and Tubiello 2007; Cline 2007). Over this period climate change could even have a positive impact in some areas due to carbon dioxide (CO<sub>2</sub>) fertilization effects. However, Lobell et al. (2008) predicted that productivity of many important staple crops may decline by 2030 in high food insecure regions, particularly in Southern Africa and South Asia. After 2050, large decreases in

**Table 2.1: Projected sources of growth in crop production to 2050 (Percent)**

	Arable land expansion	Increases in cropping intensity	Yield increase
All developing countries	21	10	69
sub-Saharan Africa	25	7	68
Near East/North Africa	-7	17	89
Latin America and Caribbean	30	17	53
South Asia	6	9	85
East Asia	2	16	81
World	9	16	75

Source: Bruinsma 2009, Baseline Scenario

<sup>4</sup> 80-85 million tonnes of cereals for ethanol production (mostly maize in the US) and 10 million tonnes of vegetable oil for biodiesel production in the EU.

<sup>5</sup> Missing or poor data required expert judgment to fill gaps on productivity and cropping intensities and problems in assessing the suitability of land use change for agriculture including lack of consideration of alternative uses such as forests, protected areas and human settlements. In addition, biophysical and socio-economic constraints to development may not be well reflected in suitability estimates, which may result in overestimates of the potential for arable land expansion. Bruinsma (2009) notes that land suitability for specific crops is more realistic than developing an overall suitability index due to these problems. In addition, potential changes in land quality (e.g. either rehabilitation of degraded lands or increases in degradation on existing lands), water scarcity, climate change impacts and biofuel expansion, which could affect yield growth and cropping intensity, are not explicitly included.

agricultural production are projected. For instance, building on assessments of six climate models and two crop modelling approaches, Cline (2007) concludes that global agricultural output could decrease between 6-16 percent by 2080, assuming a 4.4 degree increase in temperature and 2.9 percent decrease in precipitation, depending on the effects of CO<sub>2</sub> fertilization. UNEP (2009) identified increasing water scarcity arising from increased glacier melt as another potential source of agricultural production decline, leading to potential agricultural yield reductions of 1.7-12 percent by 2050 globally. Changes in pest and disease patterns could also significantly impact agricultural production (Lobell et al. 2008). South Asia and parts of sub-Saharan Africa are expected to be hardest hit in both the near and longer term, with decreases in agricultural productivity between 15-35 percent (Stern 2006; Cline 2007; Fisher et al. 2002; IPCC 2007).

Continued land degradation and water scarcity – even in the absence of climate change – could also have major impacts on future agricultural supply response. Salinization of soils, nutrient depletion and soil erosion all reduce the productivity of lands for agricultural production. In cases of advanced degradation, lands become unsuitable for agricultural production. Overall, UNEP estimates a loss of 0.2 percent in cropland productivity per year globally due to unsustainable agricultural practices (UNEP 2009).

Bio-energy constitutes a further challenge to the agricultural sector, representing the largest source of new demand for agricultural commodities in recent years. Production of biofuels, particularly ethanol and bio-diesel for use in the transport sector, has tripled since 2000 and is projected to double again within the next decade. Fischer et al. (2007) find that expansion of first generation biofuels is likely to continue to compete with food production for land and water resources, with potentially significant negative impacts on food security. However, second generation biofuel development could decrease competition for arable land use from biofuels, indicating the importance of research and development in this area (Fischer et al. 2007; Kahn and Zaks 2009).

While impacts on mean agricultural production by 2050 are expected to be limited outside of Southern Africa and South Asia, nearly all researchers conclude that increased climate variability and extreme weather events are projected to increase even in the near term, affecting all regions (c.f. Lobell et al. 2008, IPCC 2001 & 2007, Rosenzweig and Tubiello 2006). For instance, Antle et al. (1999) simulated changes in dryland grain production in Montana due to projected climate changes; model results show that impact on mean returns by 2030 were ambiguous (-11% to +6%), but that variability increased under all scenarios – both with and without adaptation. Many developing countries are already vulnerable to weather shocks, and without significant investments in agriculture, future climate changes will increase this vulnerability (Parry et al. 2007). Thus, increasing the resilience of agricultural systems is a key means of adapting to climate change as well as increasing food security.

## 2.3 Changes in agricultural practices and their impacts on adaptation/food security

The next three sections of this chapter focus on a set of changes in agricultural practices and their implications for food security, adaptation and mitigation. A consistent set of practices has been used, based on the main categories for land-based mitigation options from agriculture, identified by IPCC 2007, to assess their impacts on food security, adaptation and mitigation. It is striking that, to a very large extent, the practices needed to improve food security and adaptation are the same as those that generate mitigation.

This section starts by assessing the impact of changing practices on the level and stability of food production, the two components of food security directly linked to land use and management<sup>6</sup>. Table 2.2 provides a list of potential changes that have been proposed to increase agricultural production, as well as to decrease output variability due to climate variability and extreme climate events. Many of these options overlap with those proposed for adaptation to climate change, notably options that increase system resilience and reduce impacts of climate events on food production. A more detailed version of the table is provided in annex 7.1, and more specific examples concerning water resources are given in Box 2.1.

### Box 2.1:

#### **Mitigation options increasing system resilience: the case of water resources**

Most agriculture mitigation options have a positive impact on water resources and management. Improved cropland and grazing management can increase water storage and infiltration, reducing loss through runoff and leading to greater water availability in the soil (Molden 2007) and enhancing ecosystem water balance (Unger et al. 1991). This is true also for manure application and, in general, for other approaches that maintain or increase soil organic matter (Tilman et al. 2002; Miller and Donahue 1990). Additionally, conservation agriculture often reduces evaporation from the soil, especially in drier environments. Since the combined water loss through runoff and evaporation often leaves less than half of the rainfall (or irrigated water) available for crops, the adoption of these technologies can increase crop yields and food production.

Other technologies are more explicitly related to water management: e.g. water conservation and harvesting, and efficient irrigation can effectively increase the soil carbon pool (FAO 2008e). Terraces and contour farming also have big impacts on water, providing for storage of rainfall and discharging excess runoff through a drainage system (WOCAT 2007). Nevertheless, in areas where water management focuses on

drainage to lower water tables for crop and forage production, such as organic soils that tend to be highly fertile, there is the risk of exposing soil organic matter to aerobic decomposition, promoting substantial losses of soil carbon (Conant 2009). Other practices increase or maintain water quality: technologies that sequester carbon in grassland soils tend to maximize vegetative cover and reduce water-induced erosion and sediment load (Conant 2009).

Enhanced soil moisture should also reduce vulnerability to low rainfall and drought conditions, thus increasing the capacity of farming systems to adapt to climate change. Much of the concern over water resources in agriculture stems from a lack of moisture to maintain crop or forage production at optimal levels. This issue is particularly acute in dry land agricultural systems. Irrigation is the most common and direct way for producers to reduce water stress to crops and forage grasses, but improved cropland and grazing management have also been viable alternative strategies to improve soil water regimes. Also, in much of the world maintaining adequate moisture during extreme events is perhaps the most important aspect of adapting to future, warmer climates

<sup>6</sup> Adaptation options, which do not directly affect land use, include improved climate forecasting and their dissemination, altering timing of planting/harvesting, and developing weather-based insurance schemes (FAO 2008d, Howden et al. 2007).

**Table 2.2: Food production and resilience impacts of changes in agricultural production systems**

Food Security/Adaptation Options	Impacts on Food Production	
	Positive	Negative
<b>Cropland management</b>		
Improved crop varieties	Generally increased crop yield	
Improved crop/fallow rotations	Higher yields due to increased soil fertility	Reduced cropping intensity may compromise household food security in short-run
Use of legumes in crop rotations	Higher yields due to increased N in soil	Reduced cropping intensity may compromise household food security in short-run
Use of cover crops	Higher yields due to reduced on-farm erosion and reduced nutrient leaching	May conflict with using cropland for grazing in mixed crop-livestock systems
Increased efficiency of N fertilizer/manure use	Higher yields through more efficient use of N fertilizer and/or manure	
Incorporation of residues	Higher yields through increased soil fertility, increased water holding capacity	Potential trade-off with use as animal feed
Reduced/zero tillage	Higher yields over long run, particularly where increased soil moisture is valuable	May have limited impacts on yields in short-term; weed management becomes very important; potential waterlogging problems
Live barriers/fences	Higher yields	Reduced arable land
Perennials/agro-forestry	Greater yields on adjacent croplands from reduced erosion in medium-long term, better rainwater management;	Potentially less food, at least in short-term, if displaces intensive cropping patterns
<b>Water Management</b>		
Irrigation	Higher yields, greater intensity of land use	
Bunds	Higher yields, particularly where increased soil moisture is key constraint	Potentially lower yields when extremely high rainfall
Terraces	Higher yields due to reduced soil and water erosion, increased soil quality	May displace at least some cropland
<b>Pasture and Grazing Management</b>		
Improving forage quality and quantity	Higher livestock yields and higher quality forage	
Seeding fodder grasses	Higher livestock yields due to greater forage availability	
Improving vegetation community structure	Greater forage/fodder in medium-long term	May reduce forage/fodder in short-term
Stocking rate management	Potential increased returns per unit of livestock	Returns at the herd level may decline, at least in the short term
Rotational grazing	Higher livestock yields due to greater forage availability and potentially greater forage quality	Short-term losses likely if rotational system supports fewer head of livestock
<b>Restoring Degraded Lands</b>		
Re-vegetation	Improved yields when crops are sown in the medium-long run; improved yields on adjacent crop or grassland due to reduced wind, soil and/or water erosion	
Applying nutrient amendments (manures, bio-solids, compost)	Improved yields when crops are sown in the medium-long run	

### Impacts on Yield Variability and Exposure to Extreme Weather Events

Positive	Negative
<p>Reduced variability where varieties developed for resilience</p> <p>Reduced variability due to increased soil fertility, water holding capacity</p>	
<p>Reduced variability due to increased soil fertility, water holding capacity</p> <p>Lower variability more likely where good drainage and drought infrequent; experience can reduce farm-level variability over time</p> <p>Reduced variability due to increased soil fertility, water holding capacity</p> <p>Reduced variability due to reduced erosion and improved soil structure, increased soil fertility</p> <p>Reduced variability</p> <p>Reduced variability of agro-forestry and adjacent crops</p>	<p>Potentially greater variability with frequent droughts</p>
<p>Reduced variability in well-functioning systems</p> <p>Reduced variability in dry areas with low likelihood of floods and/or good soil drainage</p> <p>Reduced variability due to improved soil quality and rainwater management</p>	<p>May increase damage due to heavy rains, when constructed primarily to increase soil moisture</p>
<p>Reduced variability where improved forage is adapted to local conditions</p> <p>Reduced variability where seeded fodder is adapted to local conditions</p> <p>Reduced variability due to improved soil structure, reduced erosion</p> <p>Potentially lower variability in long-term, where forage availability is key factor in livestock output variability</p> <p>Potentially lower variability in long-term, where forage availability is key factor in livestock output variability</p>	<p>Potentially increased variability where improved forage is more sensitive to climate conditions than natural pasture</p> <p>Potentially increased variability where improved seeded fodder is more sensitive to climate conditions than natural pasture</p>
<p>Reduced variability in local landscape due to reduced wind, soil, and/or water erosion</p>	<p>Sources: Antle et al. 2007, Baudeau et al. 2007, Dutilly-Diane et al. 2003, FAO 2007, Freibauer et al. 2004, Giller et al. 2009, Kwesiga et al. 1999, Lal 2004, Niles et al. 2002, Nyende et al. 2007, Pretty and Hine 2001, Pretty et al. 2003, Pretty et al. 2006, Rosenzweig and Tubiello 2007, Smith et al. 2008, Verchot et al. 2007.</p>

An important point captured in the table is that impacts on food production can vary in the short versus long-run. For several options, short term impacts may be negative depending on underlying agro-ecological conditions, previous land use patterns, and current land use and management practices. Long-term impacts are expected to be positive for increasing both the average and stability of production levels. For instance, crop and grassland restoration projects often take land out of production for a significant period of time, reducing cultivated or grazing land available in the short run, but leading to overall increases in productivity and stability in the long run. A different type of trade-off may occur with incorporating crop residues that are expected to increase soil fertility and water retention capacity, thereby increasing yields at least over the medium-long term. However, where livestock are an important component of the food production system, there is a potential trade-off between residues used for the food crop system versus for livestock feed (Giller et al. 2009). This does not mean that conservation agriculture cannot be successful in areas facing these trade-offs, but rather that local farmers, researchers and extensionists must find ways to directly address these trade-offs.

While there can be trade-offs in terms of average yearly food production in the short term, there are fewer identified negative impacts on yield variability. However, yield variability can increase in the short term where changes in activities require new knowledge and experience, and farmers unfamiliar with such systems require a period to successfully adopt the practice (e.g. fertilizer application or the construction of water retention structures where incidence and severity of both droughts and floods are expected to increase in the future).

## 2.4 Agricultural mitigation options

In this section, the mitigation impacts of land use changes are assessed. The major sources of land-based mitigation from agriculture, following IPCC (2007) are described below.

### Cropland management

- Improved agronomic practices generate higher inputs of carbon (C) residue, leading to increased soil C storage (Follett et al. 2001). Such practices include using improved crop varieties, extending crop rotations, avoiding use of bare fallow and using cover crops.
- Integrated nutrient management can reduce emissions on-site by reducing leaching and volatile losses, improving nitrogen (N) use efficiency through precision farming<sup>7</sup> and improving fertilizer application timing.
- Increasing available water in the root zone through water management can enhance biomass production, increase the amount of above-ground and the root biomass returned to the soil, and improve soil organic C concentration. Soil and water conservation measures, such as the construction of soil or stone bunds, drainage measures, and irrigation constitute important aspects of water management.
- Tillage management practices with minimal soil disturbance and incorporation of crop residue decrease soil C losses through enhanced decomposition and reduced erosion<sup>8</sup>. Systems that retain crop residues tend to increase soil C because these residues are the precursors of soil organic matter.

---

7 Judicious nutrient management is crucial to humification of C in the residue and to Soil Organic Carbon (SOC) sequestration. Soils under low-input and subsistence agricultural practices have low SOC content which can be improved by judicious use of inorganic fertilizers, organic amendments and strengthening nutrient recycling mechanisms (Lal and Bruce 1999). Also, the use of organic manures and compost enhances SOC pool more than application of the same amount of nutrients as inorganic fertilizers. A combination of integrated nutrient management and precision farming, farming by soil or soil-specific management (i.e. application of nutrients and water as required for the specific soil conditions) can enhance SOC concentration, use efficiency of inputs and soil quality (Leiva et al. 1997).

- Agro-forestry systems increase C storage and may also reduce soil C losses stemming from erosion. Options include combining crops with trees for timber, firewood, fodder and other products, and establishing shelter belts and riparian zones/buffer strips with woody species<sup>9</sup>.

#### Improved grassland management

- Improved productivity through increasing nutrients for plant uptake and reducing the frequency or extent of fires (e.g. improvements in forage quality and quantity, seeding fodder grasses or legumes with higher productivity and deeper roots, reducing fuel load by vegetation management).
- Improved grazing management by controlling intensity and timing of grazing (e.g. stocking rate management<sup>10</sup>, rotational grazing, and enclosure of grassland from livestock grazing).

#### Management of organic soils<sup>11</sup>

- Draining organic soils for cultivation leads to high GHG emissions. Avoiding drainage is the best option in terms of reduced GHGs; other practices to minimize emissions include avoiding row crops and tubers, avoiding deep ploughing, and maintaining a shallower water table (Freibauer et al. 2004).

#### Restoration of degraded lands

- Carbon storage in degraded lands can be partly restored by practices that reclaim soil productivity (Lal 2004a) (e.g. re-vegetation; applying nutrient amendments and organic substrates such as manures, bio solids, and composts; reducing tillage and retaining crop residues; and conserving water).

The technical potential for mitigation options in agriculture by 2030, considering all gases, is estimated to be between 4 500 (Caldeira et al. 2004) and 6 000 Mt CO<sub>2</sub>e/year (Smith et al. 2008). Figure 2.2 rough estimates of mitigation potential from all agricultural sources by region.

The global and regional potential of the four most important sources of land-based mitigation are summarized below.

- **Cropland management:** High global potential, spread over the regions. In terms of food insecure regions, potential mitigation is particularly high in South America, Eastern Africa, South Asia and Southeast Asia.
- **Pasture and grazing land management:** Despite the low C density of grazing land, practices in this category have a high potential for C sequestration because of the large amount of land used as pastures. Data from FAOSTAT indicate that global pasture area accounted for 3 488 Mha in 2002 (69 percent of global agricultural land). On the other hand, conversion of pasture accounted for 65 percent of the increase in arable land from the 1960s to 2005. Improving pasture efficiency, therefore, will avoid further land conversion and concomitant C loss. According to IPCC (2007), potential gains are particularly high in almost all regions of Africa and Asia, as well as South America.
- **Restoration of degraded land:** Oldeman (1994) estimated that over 2 billion hectares of land were degraded. Degraded land due mainly to erosion was calculated to affect 250 Mha, including 112 Mha in Africa, 88 Mha in Asia, and 37 Mha in Latin America (Oldeman 1994). Thus, there is a large

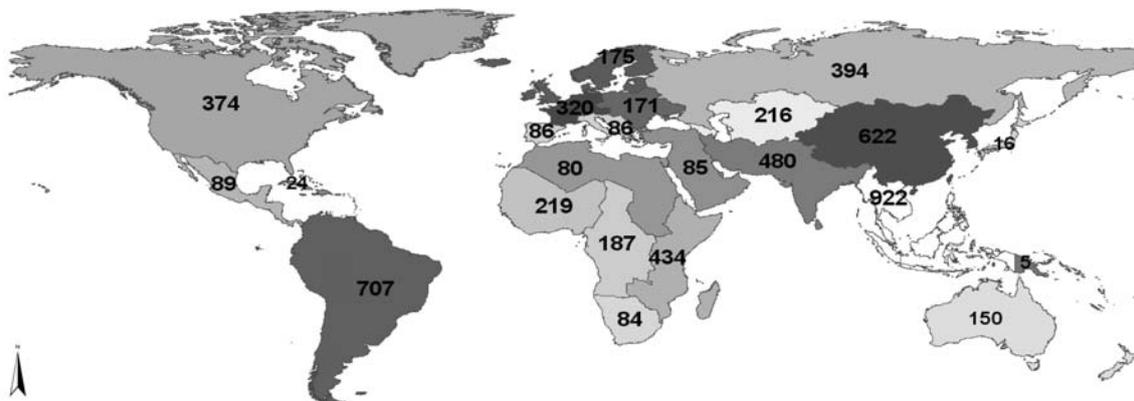
8 For example, conservation tillage (CT) is defined as any method of seedbed preparation that leaves at least 30% of ground covered by crop residue mulch (Lal 1997).

9 The standing stock of carbon above ground is usually higher than the equivalent land use without trees, and planting trees may also increase soil carbon sequestration (Oelbermann et al. 2004).

10 The intensity and timing of grazing can influence the removal, growth, C allocation, and flora of grass-lands, thereby affecting the amount of C in the soils (Freibauer et al. 2004)

11 Organic soils contain high densities of C accumulated over many centuries because decomposition is suppressed by absence of oxygen under flooded conditions. To be used for agriculture, these soils are drained, which aerates the soils, favoring decomposition and, therefore, high CO<sub>2</sub> and N<sub>2</sub>O fluxes.

Figure 2.2: Technical mitigation (all practices, all GHGs: MtCO<sub>2</sub>eq/yr) by 2030



Source: IPCC 2007, figure 8.5

potential to increase carbon sequestration in South America, East and West Africa and South and Southeast Asia through mitigation options falling within this category.

- **Restoration of organic soils:** These carbon dense soils are often important in developing countries; for example, Andriess (1988) estimated that the South East Asian region contains the largest expanse of peat deposits. The second most important area is the Amazon basin and the basins bordering the Gulf of Mexico and the Caribbean. These soils are also found in the wet equatorial belt of Africa.

## 2.5 Costs

A key consideration is the costs of achieving potential adaptation, food security and mitigation benefits from the selected set of changes in agricultural practices. This is critical in determining which synergies to pursue and which trade-offs can be effectively minimized. There are wide ranges in cost estimates by different sources, reflecting the large differences among regions and the type of costs considered in the analyses. For instance, McKinsey (2009) provides cost estimates for mitigation from crop and grassland management, restoration of organic soil, and restoration of degraded land. Average costs per tonne of carbon dioxide equivalent (CO<sub>2</sub>e) abated to the year 2030 are computed to be negative for crop and grassland nutrient management and tillage and residue management, indicating that these activities should generate higher benefits than costs over the time frame considered. While this analysis is useful in indicating which practices will be self-sustaining in the long-run, it does not indicate the magnitude of the initial investments required to make the changes, which is a main barrier to implementing many of these practices.

The few project-level costs that are available show very wide ranges due to differences in agro-ecological conditions as well as pre-project land uses and household asset endowments. Because these costs are often largely ignored, table 2.3 presents some project-level estimates of up-front establishment costs associated with the adoption of practices.

In certain cases, agronomic measures such as nutrient management or tillage/residue management have low or zero establishment costs. Nevertheless, in some cases major investments are still needed, e.g. to buy a special no-till drill to simultaneously seed and fertilize annual crops, as in the Morocco case study referenced in table 2.3. Establishing water harvesting structures may be costly but these technologies are often easy to maintain and represent a common practice worldwide. Soil and water

**Table 2.3: Adoption costs of mitigation technology options**

Technology options	Mitigation potential in developing countries (1) Mt CO <sub>2</sub> e/ha/year	Practices	Case study	Establishment costs US\$/ha
Improved cropland management	warm moist: 0.33-3.93; warm dry: 0.62-5.36	Improved agronomic practices	Natural vegetative strips, The Philippines	84
			Small level bench terraces, Thailand	275
			<i>Fanya juu terraces, Kenya</i>	320
			Vetiver grass contour lines, South Africa	140
		Integrated nutrient management	Compost production and application, Burkina Faso	12
			Improved trash lines (weed and crop residue), Uganda	n.a.
		Tillage/residue management	No-till technology, Morocco	600
			Small-scale conservation tillage, Kenya	n.a.
		Water Management	Enhanced runoff harvesting for olives, Syria	88
			Water harvesting on cropland and grazing land, India	240
Agroforestry	<i>Grevillea agroforestry system, Kenya</i>	160		
	Belters of trees for farmland, China	125		
Improved pasture and grazing management	warm moist: 0.81; warm dry: 0.11	Improved pasture management	Grassland restoration and conservation, Qinghai province, China (2)	65
		Improved grazing management	Area closure for rehabilitation, Ethiopia	390
Restoration of degraded land	3.45	Reclaim soil productivity	Restoration of degraded rangeland, South Africa	230

(1) Latin America and Caribbean, Africa, South and Southeast Asia

(2) Project estimates

Source: adapted from Wocat 2007 and IPCC 2007

conservation structures often require relatively high up-front costs in terms of labor and/or purchased inputs. Establishing agro-forestry systems requires labor costs for land preparation (which vary largely according to slope) as well as input costs for purchasing tree seedlings and fertilizers. Restoration of degraded lands can entail particularly high establishment costs that include labor and equipment needed to construct soil and water conservation structures, expenditures on seeds and seedlings for grasses and trees, and for incorporation of organic and inorganic fertilizers (Wocat 2007, Lipper et al. forthcoming).

These costs constitute a potential adoption barrier as smallholders often lack resources to make the investments needed to realize higher yields and positive net benefits in the longer run. For example, nutrient management is estimated to be highly net-profit positive on average due to a reduction in fertilizer use, and tillage management is expected to lead to a reduction in labor and fuel costs that offset increases in weed control costs at a global scale (McKinsey 2009). However, there are many other barriers to adoption of sustainable land management practices, which are well documented in

the literature (WB 2007, Nkonya et al. 2004, Barrett et al. 2002, Otsuka and Place 2001, McCarthy 2004). These barriers include not only limited credit to finance up-front costs, but also issues related to access to information, property rights and tenure security; lack of access to effective research and extension services for capacity building and technical assistance; limited access to insurance; and lack of access to markets. More extensive and country-specific analysis of costs will be needed in future.

## **2.6 Mitigation and food security: where and how can synergies be realized?**

The key regions that require urgent action to reduce food insecurity and build adaptation capacity are Central, East and West Africa, many countries in South and Southeast Asia, the highlands in South America, and certain regions of Central America and the Caribbean.

A comparison of the practices listed above with those analyzed in table 2.2 shows that nearly all of the land-based agriculture mitigation options are the same as those proposed for sustainable land management and adaptation to climate change. The potential for synergies is particularly high for changing food production practices such as adopting improved crop varieties; avoiding bare fallow and changing crop rotations to incorporate food-producing cover crops and legumes; increasing fertilizer use in regions with low N content (as in much of sub-Saharan Africa), and adopting precision fertilizer management in other regions; seeding fodder and improving forage quality and quantity on pastures; expansion of low energy-intensive irrigation; and, expansion of agro-forestry and soil and water conservation techniques that do not take significant amounts of land out of food production. Trade-offs are more likely when mitigation options take land out of production, either temporarily or permanently. For instance, restoration of degraded lands often requires that land not be used for production at least in the short-term, whereas avoiding draining or restoring wetlands would directly take land out of production permanently. Trade-offs may also be important for certain stocking rate and rotational grazing practices.

By combining information from table 2.2 with estimates of mitigation potential by practice, it is possible to derive a chart of the synergies and trade-offs between mitigation and food security for specific practices and regions as shown in figure 2.3. Because impacts will vary by agro-ecological conditions, historical land use, and current production systems, the chart is provided only to illustrate the potential synergies and trade-offs that might occur in any one location. Additionally, to simplify the chart, we consider the long-term benefits to food security in order to locate a particular practice on the chart, though it is important to recognize the short-term trade-offs that may occur. Switching from continuous cropping to improved fallow can generate moderate mitigation and food security benefits in the long term, though food production may fall in the short run. Restoration of crop and grazing lands can generate high mitigation and food security benefits, though short-medium term food production losses can be significant depending on the restoration strategy pursued. Irrigation can have very high food security benefits, but may have limited mitigation benefits (or even lead to increased emissions) where irrigation is energy intensive. Conservation and organic agriculture could be win-win, or represent a trade-off between mitigation and food production, depending on the specific use and value of crop residues and the capacity to manage weeds. Finally, management of organic soils yields very high carbon benefits, but low (and potentially negative) food production benefits. Further research is needed to derive such charts to capture the specific characteristics of different areas.

Figure 2.3: Examples of Potential Synergies and Trade-Offs

Food Security Potential	<p>Food Security Potential: High Carbon Sequestration Potential: Low</p> <ul style="list-style-type: none"> <li>Expand cropping on marginal lands</li> <li>Expand energy-intensive irrigation</li> <li>Expand energy-intensive mechanized systems</li> </ul>	<p>Food Security Potential: High Carbon Sequestration Potential: High</p> <ul style="list-style-type: none"> <li>Restore degraded land</li> <li>Expand low energy-intensive irrigation</li> <li>Change from bare to improved fallow</li> <li>Agro-forestry options that increase food or incomes</li> <li>Conservation tillage and residue mgmt, limited trade-offs with livestock</li> <li>Improved soil nutrient management</li> </ul>
	<p>Food Security Potential: Low Carbon Sequestration Potential: Low</p> <ul style="list-style-type: none"> <li>Bare fallow</li> <li>Continuous cropping without use of organic or inorganic fertilization</li> <li>Slope ploughing</li> <li>Over-grazing</li> </ul>	<p>Food Security Potential: Low Carbon Sequestration Potential: High</p> <ul style="list-style-type: none"> <li>Reforestation/afforestation</li> <li>Restore/maintain organic soils</li> <li>Expand bio-fuel production</li> <li>Agro-forestry options that yield limited food or income benefits</li> <li>Conservation tillage and residue mgmt, large trade-offs with livestock</li> </ul>
		Carbon Sequestration Potential

The key findings of the chapter are:

- There are a wide range of agricultural investment options that improve food security, increase the adaptive capacity of the food system to respond to climate change, and also contribute to mitigation.
- Synergies differ across localities, and thus a necessary first step is to identify where the potential synergies and trade-offs occur in specific circumstances.
- Even where significant trade-offs between food security and mitigation might occur from a proposed land use change, it is important to determine if there are opportunities to minimize such trade-offs.
- The costs of adoption and implementation also vary by locality, and can be significant in terms of both investment and opportunity costs.

# 3

## Enabling action on food security and climate change mitigation: financing options

Current financial resources to support changes in agricultural systems to feed the world are insufficient, while the main financing mechanisms for climate change mitigation largely exclude agriculture. This section of the paper looks at financing options – public, public-private and carbon markets – for actions that address the dual goals of food security and climate change mitigation from agriculture in the context of sustainable agricultural development.

There are several options for financing mitigation actions currently under negotiation that vary in suitability for agricultural mitigation across different countries. These foresee the use of public and private sources of finance, including market mechanisms, and range from project to sectoral levels. One of the key issues associated with establishing financing mechanisms for mitigation is the establishment of systems to measure, report and verify mitigation actions and outcomes. The type and cost of MRV systems could vary by financing source. This chapter discusses some of the main MRV options in the context of various financing mechanisms and their potential for application in agricultural mitigation actions in developing countries.

### 3.1 Agricultural investment requirements vis-à-vis climate financing

In the framework of the FAO work on “How to Feed the world in 2050”, Schmidhuber et al. (2009) estimate that cumulative gross investment requirements for agriculture in developing countries add up to nearly US\$9.2 trillion until 2050 or nearly US\$210 billion annually<sup>12</sup>. Comparing this with the estimate of the total annual value from the four major mitigation categories (crop and grazing land improvements, organic soil and degraded land restoration) in non-OECD countries of 1.5 Gt/CO<sub>2</sub>e/yr<sup>13</sup>, and valuing these at \$20/t CO<sub>2</sub>e, US\$30 billion could potentially be generated annually through agricultural mitigation (IPCC 2007). This very rough estimate indicates that carbon finance could be a significant, although insufficient, source of funds for agriculture in developing countries that needs to be taken into account in agricultural planning and policy. Further value can be captured by integrating the investments needed for agricultural development and agricultural mitigation. Potential areas of overlap and savings still need to be quantified, however.

The estimates above also indicate the potential limitations of carbon finance in agricultural investment needs: carbon finance may never contribute more than 15 percent of the overall agricultural investment needs. Considering the strength of the financial muscle of agricultural carbon finance, a combination of long-term international ODA and carbon finance could finance programmes to:

- Leverage public and private investment in adopting sustainable and resilient forms of agricultural production that also enhance mitigation as well as other ecosystem services. This includes

<sup>12</sup> This estimate, like those presented in chapter 2, assumes an 11% per capita calorie increase and food insecurity remaining at 4% of the population by 2050. About 39% of the investment demand is in China and India, 61% has to be invested in agriculture across all other developing countries. Investment costs for agricultural research, rural infrastructure and capacity to trigger the transition are not included. Costs for bringing degraded land into production are also not considered.

<sup>13</sup> Economic agricultural mitigation potential: for cropland improvement including rice management 0.62 GtCO<sub>2</sub>e/yr, grazing land improvements 0.62 GtCO<sub>2</sub>e/yr, organic soil restoration 0.17 MtCO<sub>2</sub>e/yr, and restoration of degraded lands 0.17 GtCO<sub>2</sub>e/yr, (IPCC 2007)

agriculture in ecological zones that have a large sequestration potential and are important for human survival such as watersheds of major rivers and areas with high biodiversity.

- Remove investment barriers for adopting management activities that have substantial long-term food security, agricultural productivity and climate benefit gains, such as restoring degraded lands in high productivity zones.

In order to mobilize long-term public and private finance for agricultural mitigation and development from public and private sources, different financing mechanisms related to international sources of funds will be needed. To enable these sources of financing, a regulatory framework and enabling conditions for investments are required. A range of options for financial mechanisms are briefly introduced below.

### Climate financial mechanisms

Securing adequate and sustainable sources of international finance to support the adoption of mitigation activities in developing countries is a major issue in the climate negotiations. Climate change financing is not about aid with donors and recipients, but cooperative public and private action considering common but differentiated responsibilities (Neuhoff et al. 2009). Different financing mechanisms have to be coordinated to reach the scale required to meet agricultural production and climate change challenges. Criteria for assessing the financing options include the need to address issues of equity, differentiated responsibilities and regional representation and relevance. Financing can play two main functions in the implementation of agricultural mitigation actions:

- **Direct finance** to cover incremental costs of implementation, which can include capacity development, or financing to overcome agricultural mitigation adoption barriers such as capital access for smallholder farmers and agricultural inputs and opportunity costs associated with adoption (see chapter 2).
- **Facilitating financing** to establish the conditions and incentives for other stakeholders to invest in agricultural mitigation. This can include the development of robust policy frameworks that facilitate smallholder access to land and capital such as micro-finance schemes. Facilitating financing could be used to enable private sector financing as well.

These two forms of finance can support three main categories of mitigation costs:

- **Up-front finance**, in particular from developed countries, is necessary to develop a public-private financing architecture. Up-front financing is crucial for capacity building but also for smallholder farmers to obtain agricultural inputs to increase yields and enhance carbon sequestration. However, in some case, maintaining improved long-term agricultural practices will require that, up-front finance be combined with finance provided during operations.
- **Operations financing** can be generated through the cash-flow from the up-front investment or the adoption of the mitigation action. Extension is an important service that can benefit from operational financing to improve the uptake of research and to ensure that research is demand driven. Payments for ecosystem services are one potential source of operation finance as shown by experiences in a number of developing countries.
- **Risk coverage** is particularly important to facilitate the adoption of new technologies and to mitigate climate risk.

Financing mechanisms can also be supportive of the transition to nationally appropriate forms of climate smart development. Agricultural mitigation has considerable potential to address equity and regional representation issues: it is one of the most relevant types of mitigation actions open to least developed countries and its implementation can affect the poorest segments of the populations. The following section reviews the major financing mechanisms under negotiation for mitigation in developing countries within the framework of agricultural mitigation.

### **Climate financing sources**

One of the main issues under negotiation is how to support mitigation actions, particularly in developing countries. Several options are on the table. For example, financing could be provided from a multilateral fund on climate change receiving the proceeds from a carbon tax on international aviation, maritime transport or from auctioning Assigned Amount Units (AAUs). While a comprehensive analysis of the various options for financing mitigation actions in developing countries is outside the scope of this report, considerations of how mitigation finance could be linked to ODA is clearly critical given the analysis of the potential role of agricultural mitigation finance presented above.

Financing of agricultural mitigation should derive from new and additional resources. ODA for agriculture is not intended for financing agricultural mitigation, but could be directed at actions that will contribute to agricultural development and food security and facilitate the implementation of mitigation actions. ODA could be used to provide budget or sectoral financing support for capacity building for developing changes in agricultural production systems that are likely to generate food security as well as mitigation benefits. Uncertainty and fluctuations in public and private funding (including markets) indicate the need to identify means for achieving long-term sustainable financing mechanisms to attain and maintain desired levels of agricultural mitigation and agricultural development. Utilizing multiple funding streams, including mitigation financing mechanisms, whether fund or market-based, could offer this potential.

### **Climate financing vehicles for agricultural mitigation in developing countries**

Agricultural mitigation actions could be high priority candidates for Nationally Appropriate Mitigation Actions (NAMAs) in LDCs, where agriculture constitutes a highly climate sensitive and economically important sector of the economy. In higher income countries with more diversified economies, agriculture-inclusive NAMAs also have significant potential to contribute to emissions reductions while improving incomes and livelihoods of some of the poorest sectors of the population. Due to their multiple benefits and the need for strong technical and institutional support in the agricultural sector, agriculture-inclusive NAMAs may require an integrated approach with agricultural policy and development at the country level. Most critical for developing countries is that NAMAs or any other agricultural mitigation financing mechanism must have national ownership and be supportive (or at least not harmful) to national development processes. See annex 7.7 for more background on NAMAs for agriculture land management in developing countries.

Possible establishment of dedicated funds for mitigation in developing countries: Some agricultural mitigation activities with positive impacts on food security will not be appropriate for financing from carbon markets or private sector due to high transactions costs or other investment barriers. Limited capacity in many countries and regions will also limit the extent to which market approaches could be utilized, at least in initial phases of development. For these reasons it may be necessary to finance agricultural mitigation activities through global multilateral climate funds. Some possible options include: the establishment of one

global climate fund, or funds specifically dedicated to agricultural mitigation within or outside the global fund. There are various proposals for how this fund could be established and managed. For example, Mexico has proposed the establishment of a Green Fund, to be financed by contributions from all countries according to the principle of common but differentiated responsibilities. Factors that need to be considered include the potential for establishing long-term and reliable funding sources, the potential for conflicts due to multiple fund objectives and the need for specific financing procedures to support agricultural mitigation.

Linking with carbon markets: Relying solely on public finance significantly reduces potential financial resources for agricultural mitigation. Therefore a step-wise approach to linking NAMAs to carbon markets could be considered. This would largely be based on country capacity and experience; building MRV capacity would increase the ability of countries to tap into market sources of finance.

Linking to Reducing Emissions from Deforestation and Forest Degradation (REDD) plus mechanism: Financing for agricultural mitigation could be integrated into REDD plus funding sources and/or eventual financing of NAMAs (if REDD plus is integrated into NAMAs), possibly including the existing Clean Development Mechanisms (CDM). However, as the development of a REDD plus financing mechanism is well advanced and financing requirements are different, this option could result in the marginalization of agricultural mitigation actions and not capture their full benefits. Linkages between different land-based mitigation actions could be explored by designing similar but parallel phased funding and implementation mechanisms for forest and agricultural land-based mitigation.

## 3.2 MRV requirements for different financing options

MRV systems are needed to ensure the environmental and social integrity of mitigation actions. MRV systems vary depending on their scale and degree of confidence associated with the estimates they provide. The costs also vary depending on these same factors, as well as by different types of mitigation actions (See box 3.1 for a discussion on measuring changes in soil carbon stocks and annex 7.2 for a detailed discussion of MRV for agriculture mitigation). In this section, existing and proposed MRV options for various financing mechanisms are presented and discussed in relation to their application to agricultural mitigation actions. This is followed by a brief overview of the cost implications related to different MRV systems.<sup>14</sup>

### 3.2.1 National GHG inventory

The IPCC Good Practice Guidelines (2003) for land use, land-use change and forestry (LULUCF) published detailed GHG inventory and monitoring guidelines for all land-based emissions and removals. National GHG inventories are needed to monitor the impact of mitigation action at sectoral level in the framework of internationally supported NAMAs.

National soil GHG inventories based on Tier 1 approaches require quantitative information on land use, management and climate and soils distribution in order to predict carbon stock changes related to land use change and the adoption of certain management activities. Default values for carbon stocks and stock change factors, for specific land use and management options (i.e. activity-based default values) are provided by IPCC (2006). Moving from Tier 1 to Tier 2 requires country-specific estimates of carbon stocks, stock change factors and emission factors. Tier 3 approaches require the most detailed

---

<sup>14</sup> The background and context for outlining options contained in this section were provided by the following documents: Ellis and Moarif (2009) highlighting what needs to be MRVed with a focus on the different metrics and reporting intervals; Breidenich and Bodansky (2009) on legal context of MRV requirements; McMahon and Remi (2009) on the different MRV country positions in the climate negotiations; and UNFCCC submissions by parties.

### Box 3.1

#### Measurement of soil carbon stock changes

Advanced capabilities exist on reliable and cost-effective systems for measurement and monitoring of agricultural soil carbon (C) stock changes and nitrous oxide (N<sub>2</sub>O) flux. Priority investment needs are to develop a limited but high-quality network of soil benchmark monitoring sites and to develop improved software packages that help integrate geospatial data (climate, soils), management activity data and appropriate soil carbon models.

Options to quantify soil C stock changes for implementing MRV for agricultural soils include: 1) direct measurements of soil C changes; and 2) a combination of activity-monitoring and C estimation models. A brief description of the approaches is detailed below.

**Direct measurement:** Overall, the technology to accurately measure soil C contents exists and is widely available at reasonable cost<sup>15</sup>. Thus the challenge in measuring SOC stock changes is not in the measurement technology *per se* but rather in designing an efficient sampling regime to estimate soil C stocks at field-scales. The spatial variability of SOC is often high (Robertson et al. 1997) and the amount of C present in the soil (i.e. background) relative to the change rate is typically high; thus there is a low 'signal to-noise' ratio.

Hence a 5-10 year period between measurements is typically needed to adequately detect the cumulative change (Conant and Paustian 2002; Smith 2004).<sup>16</sup>

**Integrated activity monitoring and carbon modeling approaches:** These approaches build off of field monitoring data and mathematical models of how soil carbon changes in response to specified changes in land use and management. There is considerable knowledge on the general responses of soils to management and land use change, primarily derived from long-term field experiments<sup>17</sup>. A number of reviews, syntheses and meta-analyses of agricultural soil C stock dynamics have been published in recent years (Ogle et al. 2004, 2005; Paustian 1997ab; West and Post 2002) summarizing these data and providing estimates of soil C change for various management practices. This integrated approach is used in national-level soil C inventories reported to UNFCCC (Lokupitiya and Paustian 2006) and for project-level accounting (Antle et al. 2003; Smith et al. 2007). However, there are limitations in these approaches that need to be addressed to increase the accuracy of agricultural MRV approaches over time.

environmental and land use and management data. In most cases, available data, e.g. through FAO and in-country sources, are sufficient for Tier 1 estimates but capacity and resources for compiling and analyzing the information is the main limiting factor. For higher tiered approaches, additional data collection and research capacity is needed beyond what currently exists in most non-Annex I countries<sup>18</sup> and may entail significant costs. See annex 7.5 for a list of FAO sources of data relevant for MRV.

### 3.2.2 MRV for NAMAs

It has been suggested that NAMAs could provide an over-arching structure for different action categories:

- actions undertaken by developing countries and not enabled or supported by developed countries (unilateral mitigation actions);
- actions supported by a fund and financed by developed countries (supported mitigation actions); and
- actions that are undertaken to acquire carbon credits (creditable and or tradable mitigation actions)<sup>19</sup>.

<sup>15</sup> Sample analysis costs for automated CN analyzers in the US are typically in the range of \$3-4/sample. The main costs once samples have been taken from the field are in sample preparation, i.e., sieving, drying, grinding, and weighing, much of which involves hand labor – hence sample preparation costs are largely determined by local labor costs.

<sup>16</sup> These remeasurement intervals are similar to those used in forest inventories for determination of biomass increment.

<sup>17</sup> There are a few hundred long-term field experimental sites globally, in which soil carbon has been measured (for up to several decades) in replicated management treatments consisting of crop rotations, tillage management, fertilizer levels, irrigation and manuring, often with more than one treatment variable in combination. The majority of these are located in temperate regions (e.g., Europe, North America, Australia/New Zealand), but a large number long-term experiments with measurements of soil C also exist in China, India, and South America, but only a few such sites in Africa.

Depending on the NAMA category, varying levels of detail and accuracy for MRV might be appropriate. A minimum set of MRV obligations might be required for unilateral actions, if they are to be internationally recognized. For actions supported by developed countries, additional MRV responsibilities may be necessary to ensure that the investments have the desired climate impact. Finally, substantial MRV capacity has to be first established before robust MRV systems can operate that enable NAMA crediting and trading mechanisms.

### 3.2.3 MRV for crediting and trading approaches

There is a wide spectrum of possible approaches ranging from public funded policies to crediting mechanisms, with the latter mirroring some of the proposals being made under CDM reform.

The main options for crediting agriculture mitigation under sectoral mechanisms are related to:

- Programme of activities (PoA) using regional baselines; and
- Sector, or potentially sub-sector, approaches based on crediting or trading approaches (e.g. lose or no-lose targets)

Bottom-up accounting methodologies developed for specific mitigation activities under the CDM could be used to provide guidance on:

- the methodology applicability conditions;
- the baseline, i.e. carbon stocks and carbon stock changes in a without-project scenario;
- estimating emission reductions and removals for the project scenario; and
- monitoring the emission reductions and removals.

The development of land-based agricultural mitigation methodologies could augment these existing approaches, with consideration of specific agricultural mitigation characteristics. Baseline development procedures could be informed by the ongoing relevant REDD initiatives. The principal approaches that are important pre-conditions to ensure the environmental integrity of agricultural mitigation, i.e. preventing leakage and ensuring permanence and additionality, can also benefit from the experience in the forestry sector and the evolving voluntary carbon standards. Considering that land-based accounting may move towards a comprehensive landscape approach (see FAO 2009b), the terminology introduced in the context of REDD could be used (Angelsen et al. 2009).

One of the most promising crediting approaches for agriculture is a programmatic approach, also referred to as program of activities (PoA). Activities based on a single approved methodology can be adopted independent from the sector as a whole and activities can be implemented by different operators, e.g. the private sector or NGOs in a specific geographical region. Compared to stand alone projects, individual activities do not have to demonstrate additionality or be individually validated, and a regional baseline could be used for land-based activities. This would dramatically reduce carbon related transaction costs. The approach provides the flexibility to up-scale promising agricultural mitigation activities, e.g. sustainable rangeland management over millions of hectares, while benefiting from the reduced transaction costs of the programme framework. Furthermore, the different approaches are already eligible with CDM crediting mechanisms and thus can be linked to existing trading systems.

---

18 However, many of the larger non-Annex I countries (e.g. Brazil, China, India, Mexico) have the scientific infrastructure to support higher tier inventory approaches.

19 [http://unfccc.int/files/meetings/ad\\_hoc\\_working\\_groups/lca/application/pdf/mitigation1bii140808\\_1030.pdf](http://unfccc.int/files/meetings/ad_hoc_working_groups/lca/application/pdf/mitigation1bii140808_1030.pdf) (page 4 referring to negotiation text page 94: alternatives to paragraph 75, alternative 2).

#### BOX 3.2:

#### Concept for a rangeland management PoA in China

Rangelands cover about 400 million ha or more than 40% of China's territory, and nearly the same proportion of the Earth's land area. In China, as elsewhere, large areas of grassland are degraded due to unsustainable management practices. McKinsey and Co (2009) concluded that adopting sustainable grassland management and restoration practices in China is the most important abatement opportunity in China's agricultural sector up to 2030, with an abatement potential of 80 million tonnes of CO<sub>2</sub>e.

In provinces like Qinghai, with about 36 million ha of grasslands, a PoA management approach could include a regional baseline established at the province or the prefecture level<sup>20</sup> while project activities could be implemented at county level.

Close horizontal and vertical coordination between government agencies and an integrated planning and funding mechanism would be required. Activity monitoring information could be also aggregated at prefecture level. Carbon modeling to predict the mitigation potential of certain management activities could be produced by local research institutes. At village level, community organizations and village committees with technical support from the county grassland management station could conduct participatory land-use planning. The planning process would define the carbon baseline and the management activities that can be adopted to achieve the dual goal of restoring soil carbon stocks while increasing household incomes.

### 3.2.4 MRV for support

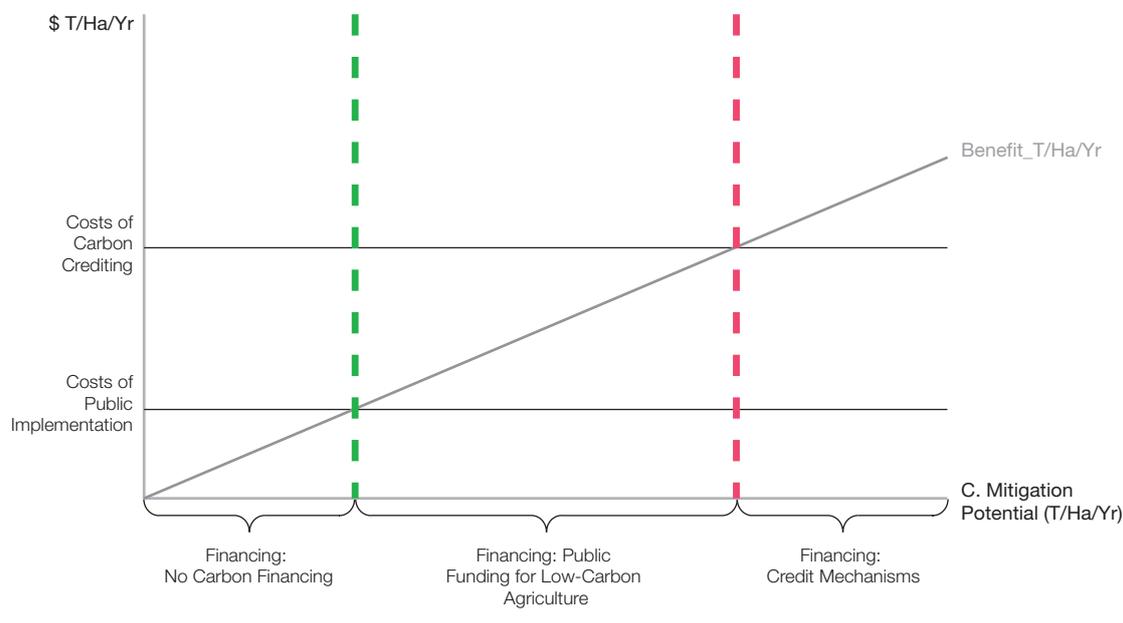
Developing countries need support to adopt mitigation actions, reflecting country-specific needs and capacity. Financing can be provided via dedicated multilateral or bi-lateral agreement, and requires a mechanism to trace and monitor support. One option is to build on a system used by the Development Assistance Committee of the Organisation for Economic Co-operation and Development (OECD-DAC) to track all ODA provided by its members. Different options to quantify the support provided would need to be examined. Capacity support and technology could be valued at cost, i.e. at research or expert input costs, priced at market value or by valuing the resulting mitigation and adaptation impacts.

## 3.3 Economics of MRV

The costs associated with different MRV systems in particular will affect which activities should be pursued in order to gain carbon credits versus those that could be financed through public sources – either national or international. Additional costs include the transactions costs associated with enabling farmers to adopt low-carbon strategies, as discussed in section 2. To highlight the relationship between financing and mitigation potential, figure 3.1 illustrates how costs of adopting, monitoring, reporting and verifying carbon mitigation activities influence the nature of financing as the potential to sequester or reduce emissions increases per hectare. As in figure 2.3, the horizontal axis represents the potential to increase carbon sequestered or reduce emissions per hectare per year (Carbon Mitigation Potential (T/Ha/Yr)), which depends on the type of soil, agro-climatic zone and previous and current land use<sup>21</sup>. The vertical axis represents the monetary costs and benefits from carbon mitigation activities. As the amount mitigated increases per hectare per year, the value of mitigation increases, as shown by the upward sloping Benefits\_T/Ha/Yr line, where T/Ha/Yr indicates tonnes of carbon mitigated per hectare per year. Two potential costs are also shown: higher costs associated with accessing carbon credits that may be then sold on the private market; and lower costs associated with public financing.

<sup>20</sup> In Huangnan Prefecture, Qinghai Province, where Government agencies together with FAO, ICRAF-China and the private sector are exploring opportunities for rangeland mitigation activities, grasslands cover 3.5 million ha (85% of the prefecture's land area). The target county, Zeku County, has 0.65 million ha of grassland covering 98% of the county's land area.

Figure 3.1: Financing Costs and Carbon Mitigation Potential



Activities to the right of the red dotted line capture those activities where C crediting mechanisms are suitable since the benefits in terms of carbon mitigation are greater than the costs of adoption and of meeting carbon crediting MRV requirements. Those to the right of the green line indicate activities where the benefits to pursuing low-carbon agricultural strategies are greater than the costs associated with adoption of basic MRV, therefore non-crediting mechanisms like Policies and Measures (PAMs) outside the carbon market or Sustainable Development Policies and Measures (SDPAMs) may be most appropriate to trigger a low carbon agricultural development pathway. Activities to the left of the green line indicate activities for which there are limited opportunities to pursue carbon mitigation, because adoption costs and/or MRV costs are high relative to the mitigation benefits to be realized.

The simple graph above captures a static picture of representative costs and benefits. Investments made now can also decrease the costs of both accessing carbon crediting and costs of pursuing low-carbon strategies in the future.

### 3.4 Conclusions

The key conclusions on financing and MRVs for agricultural mitigation actions in developing countries that emerge from this chapter include:

- Structured and phased financing mechanisms are crucial for agricultural development and to enable agricultural mitigation actions in developing countries.
- Considering the size of the overall required agricultural investments versus the potential income from carbon credits, carbon finance is significant, but more important is shifting agricultural investments towards climate smart agricultural development, that capture synergies or mitigate potential trade-offs.

21 In terms of sequestration, the amount sequestered per year will change each year until saturation levels are reached. This simple graph can best be thought of as representing the average increases per hectare per year.

- Financing is needed for both direct and facilitating actions to enable mitigation, with the former directed at meeting the capacity building, investments and operating costs associated with mitigation actions, and the latter directed at creating frameworks and institutions that enable and incentivize financing from other public and private financing sources.
- National ownership in the design and implementation of NAMAs is critical for their success, and mitigation actions that have synergies with the national development processes are those most likely to succeed.
- Currently, there is no consensus on MRV needs for financing mechanisms, but clearly decisions in this regard will affect the costs and viability of different agricultural mitigation activities. However, to make these systems operational, there is a need for development of capacity and methodologies as well as field level pilot activities, to improve and scale various approaches over time in a phased approach.

## Moving from negotiations to implementation: options for action

This chapter provides a proposal for taking forward the work needed for realizing the potential of agricultural mitigation in developing countries using a phased approach. Moving forward will require action at both national and international levels.

### 4.1 Anchoring agricultural mitigation at the international level

#### 4.1.1 High level political commitment

Meeting the dual challenge of achieving food security and mitigating climate change requires political commitments at the highest levels. Two major international meetings at the end of 2009, the World Summit on Food Security (Rome, November 2009) and the UNFCCC COP15 (Copenhagen, December 2009), offer opportunities for a more holistic vision and more appropriate integration of agendas for food security and climate change. This can help to open the door to action that captures synergies and manage trade-offs across these two key challenges.

#### 4.1.2 Building international confidence in agricultural mitigation

The analysis presented in this paper has indicated several areas that need further investigation, analysis and clarification before effective implementation of agricultural mitigation can begin. Resolving outstanding methodological questions and building readiness for implementation of agricultural mitigation are needed in order to gain the necessary level of international confidence to support agricultural mitigation in developing countries on a significant scale.

A COP mandate for a SBSTA programme of work on agricultural mitigation in developing countries could provide a vehicle for systematic consideration and debate of outstanding technical issues that could facilitate agricultural mitigation actions in developing countries.

Possible key elements that a SBSTA programme of work could address include:

- Modalities of implementation for different NAMA categories as outlined in this report and agreements for defining a phased implementation approach;
- MRV approaches for various financing options;
- Means of ensuring that benefits from early agricultural mitigation action are enabled to provide incentives for innovation and investments;
- Assessment of the potential for fast-tracking sectoral and programmatic approaches to agricultural mitigation from land-based sources in order to realize cost-effective mitigation in the near term.
- Reference levels for agricultural mitigation.

### **4.1.3 Establishing an international network of agricultural carbon pilots**

Currently, there is limited practical experience on how to integrate carbon finance in smallholder crop and livestock systems as a livelihood enhancing source of income. Sub-national pilot projects, embedded in a global and country-driven support and learning network, will be important in assessing the extent and means of cost effective implementation of agricultural mitigation activities that support food security as well as other co-benefits. Pilots are also necessary to inform implementation models and as a basis for exploring the viability of programmatic and sectoral up-scaling and MRV mechanisms.

One option for fully exploiting the potential benefits of pilot activities is the possibility of establishing a coordinated network of pilot project activities together with national partners. Recognizing the need to facilitate real transactions, an Agricultural Carbon Finance Platform involving private and public investors could be established to mobilize carbon funds for pilot projects.

### **4.1.4 Securing long-term financing and partnerships: in search of the champions**

Securing adequate and sustainable streams of financing is a critical next step that could be embedded in the ongoing discussions of financing agricultural development, as well as mitigation in developing countries.

The role of government is crucial in providing a supportive policy framework for climate mitigation actions. The private sector can play a role in the provision of technical and process innovations and to upscale local investments that have global food security and climate benefits based on existing platforms, such as the Sustainable Agriculture Initiative and the Sustainable Food Laboratory group. Civil society plays a role in advocating for and enhancing related social and environmental integrity safeguards. Multilateral organizations, including those focusing on agriculture, are well positioned to facilitate partnerships and to support a consensus building process that this report aims to initiate. Finally, donor champions are needed to support a wide consultation process and early mitigation actions.

## **4.2 Anchoring agricultural mitigation at the country level**

### **4.2.1 Ensuring nationally appropriate action**

Nationally appropriate agricultural mitigation actions must be grounded in country-led and owned national development strategies and processes. Effective implementation of agricultural mitigation on any significant scale in developing countries will require integration into existing agricultural institutions and policies, such as research and extension services, financial mechanisms and institutions that govern rights of access to resources. However, in many developing countries these institutions, particularly those that serve smallholder farmers, would benefit from capacity building. The integration of agricultural mitigation programmes into agricultural development strategies will thus need to be part of the overall effort to improve the sector's performance and the livelihoods of small farmers. FAO is currently developing guidelines for integrating mitigation and adaptation into agricultural planning (Bockel and Smith 2009). In Box 4.1, we outline various national-level policy options for including smallholders in mitigation actions that are embedded in integrated rural development plans.

### **4.2.2 Prioritizing agricultural mitigation actions**

Countries considering the potential of agricultural mitigation for inclusion in NAMAs can tailor programmes to fit their national capabilities and circumstances through a process of prioritization of mitigation actions. The analyses provided in chapters 2 and 3 provide important insights into the factors

**BOX 4.1:**

**Policy Recommendations at the National Level, Potential Next Steps**

**1. Reaching Smallholders**

- a. Legal Framework: Define ownership of rights to receive payments for environmental services (e.g carbon sequestration), define who has rights to purchase which services, determine management and allocation of the risk of non-performance or incomplete performance, and devise dispute resolution mechanisms.
- b. Institutional Framework: Devise policies to reduce transactions costs of smallholder participation, e.g. networks and mechanisms to aggregate smallholders.

- c. Market Regulations: Ensure that such regulations do not distort incentives for smallholders to invest in sustainable land management practices.

**2. Integrating Agricultural Mitigation and Adaptation Actions into Rural Development Plans**

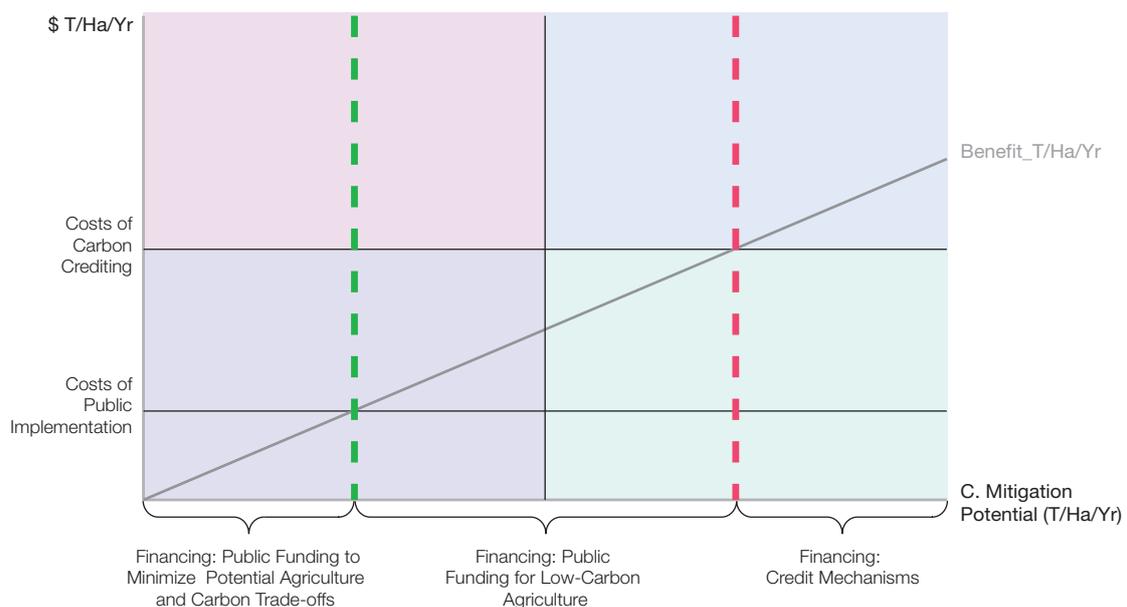
- a. Ensure policy coherence across ministries and in support of development plans.
- b. Ensure that research, training and capacity building reflects the synergies between food security, mitigation and adaptation.

**3. Prioritizing Actions, to ensure that external funding is country-led.**

countries can consider when prioritizing actions: their impacts on food security and adaptation to climate change, as well as their costs of implementation and MRV requirements necessary to secure financing. Figure 4.1 shows the potential synergies and trade-offs by overlaying figures 2.3 and 3.1.

Quadrants in the upper half of the figure capture those activities that increase food security. Those in the right hand quadrant capture high carbon mitigation potential. Activities in the upper right hand quadrant to the right of the red dashed line represent win-win activities that can also be financed through the carbon credit market. Activities in the lower quadrant to the right of the red line represent activities where carbon mitigation activities can still participate in carbon markets, but where impacts on food security are relatively low. Activities to the right of the green line and in the upper quadrants represent win-win activities that can

**Figure 4.1: Synergies and Trade-offs in Food Security and Carbon Mitigation**



be financed through public funding. On the other hand, activities in the upper left-hand quadrant represent agricultural growth opportunities that have large impacts on food security, but with minimum carbon sequestration potential so that sources other than carbon financing would be required. However, even in these cases, it may be possible to shift these food security beneficial practices into a climate smart strategy in the future with public investments. Synthesizing the information on the potential mitigation and food security benefits from potential changes in agricultural systems with information on costs and barriers to adoption will yield an indication of where the best options lie for obtaining synergies between mitigation and food security. This same analysis will also give insights into the type of carbon financing mechanisms that might be best used for realizing the mitigation benefits. However, in order to be able to conduct such an exercise, country-level information must be collected and/or collated. Research and data management both provide instances where investment decisions in the agricultural sector made now can contribute to realizing the goals of increased agricultural growth, food security and carbon mitigation.

The increased availability of information from spatially referenced databases will be particularly useful for identifying potential synergies and trade-offs. In addition to the map of technical mitigation potential found in IPCC (2007), FAO has produced a map of the “carbon-gap” that allows for the identification of areas where increases in soil carbon storage are potentially greatest (FAO 2007). Overlaying the FAO Carbon-Gap and Hunger Maps reveals that countries and regions with large food insecure populations often also have large carbon-gaps, which result in low-yield production and increased climate vulnerability (see annex 7.6). Additionally, models are being developed to estimate the mitigation potential and food security benefits from changes in agricultural production systems, such as the Ex-ante Appraisal Carbon-Balance Tool (Ex-Act) presented in annex 7.3.

Country-level analyses of the implementation costs and barriers are also needed. Adopting the marginal abatement cost curve assessment approach (see McKinsey 2009) is one way of identifying options that are likely to generate long-run net social benefits. However, further information on initial investment costs at the farm level, as described in chapter 2, is required, along with the additional institutional and infrastructure investments required to ensure sustained adoption. In particular, institutional investments are needed to develop carbon value chains and to ensure that smallholders participate fully. These investments are considered in the sections below.

Most countries will face both mitigation and adaptation challenges. It is important to assign high priority to mitigation actions that have strong adaptation benefits. Lower priority could be assigned to mitigation activities that have no adaptation benefits. Financing preferences should generally go to the former, and a top-up based on the adaptation asset value could be considered. MRV systems to quantify the adaptation asset value, based on mutually agreed accounting units would need to be developed. Combined mitigation and adaptation activities are expected to reduce substantially transaction costs.

#### **4.2.3 Assessing potential institutions for a carbon value chain**

The value chain approach provides a useful framework to understand the institutional requirements and the steps involved for removing carbon and reducing emissions. The required institutions to establish an agricultural carbon value chain may exist already, but in order to fulfill their role, capacity building may be required and a business model may need to be adapted.

Carbon value chains can be either integrated into an agricultural commodity chain or included in a landscape or watershed integrated management approach. The different institutional requirements result in distinct institutional arrangements (See box 4.2 presenting respective pilot initiatives). When carbon is integrated into an agricultural commodity chain there is a strong market pull factor. For example, adopting best coffee management practices often results in more coffee and additional carbon

removals. However, without sufficient incentives, adoption barriers such as the lack of specialized extension providers can not be overcome. In a landscape setting, a large variety of agricultural practices exist and a number of new mitigation practices can be adopted. However, given that many different management objectives and cropping systems exist and interact, mitigation actions have to be identified via farmer needs assessments and participatory planning exercises, so that broader implementation support can be provided through the value chain.

#### **4.2.4 Making the link to smallholders—what is needed?**

Ensuring that smallholders can and will participate in such mitigation actions will require specific actions at the country level. Mirroring similar debates in the REDD context, Angelsen et al. (2009) identified three main principles for promoting the effective participation of indigenous peoples and local communities that are also applicable in the agricultural context: 1) rights to land, territories and resources including ecosystem services; 2) representation in decision making at international and national levels, including access to dispute resolution mechanisms; and 3) integration of mitigation actions into long-term development plans. Lessons from payment for environmental service programmes indicate that such programmes can promote equity by providing alternative sources of income, expanding asset endowments and promoting vehicles for better governance and regional management (Wunder 2006; FAO 2007).

Supporting existing institutional arrangements to aggregate mitigation actions across a large number of smallholders are a necessary preparatory step. Institutions such as group credit schemes, existing community-based natural resource management programmes, farmer field schools and other farmers' organizations and women's groups can all be innovative options to provide required arrangements.

Managing risk is needed to facilitate the participation of smallholder farmers. Index-based weather insurance contracts for smallholders could provide some important lessons on how to cope with climate risks and for designing carbon payment programmes (Lipper et al. forthcoming; Osgood 2008).

##### **BOX 4.2:**

##### **Integrating soil carbon payments into small-holder value chains in Kenya**

The Government of Kenya, with support from the World Bank BioCarbon Fund, started two soil carbon sequestration pilot projects together with partner organizations. One project in the Mount Kenya region promotes the adoption of mulching, agroforestry and soil erosion control activities in small-holder coffee and mixed cropping systems. The 9000 farmers organized in the Komothai Smallholder farmer's cooperative will use the carbon revenues to invest in better coffee management that is expected to increase coffee yields from currently 1.5 kg to 5 kg per tree. ECOM Agroindustrial Corp, the international coffee marketing agent of the cooperative, acting as an aggregator between the Carbon Fund and the Cooperative, is supporting farmers to produce certified quality coffee by providing targeted extension and certification support. Farmers

receive 100 percent of the carbon revenues in this scheme to bridge the initial investment gap between the adoption of best coffee management practices, until the investment increases farm income from coffee and crop production for subsistence use. The other pilot project in Western Kenya with sub-projects in the Kisumu and Kitale, areas are using a landscape/watershed approach. Registered farmers' associations representing 80 000 small-scale farmers together with the NGO VI Swedish Cooperative Centre are adopting SALM practices including agroforestry to improve people's livelihood and to enhance the resilience of farmers to cope with climate change. The carbon project covers an area of 86 000 ha and is expected to generate 2.2 tCO<sub>2</sub>/ha/year of additional terrestrial carbon (soil and biomass carbon).

#### **4.2.5 Building confidence and readiness for implementation**

Differing national capacities and circumstances indicate that phased approaches are needed to enable transitioning towards sustainable development that can meet national economic development, food security and mitigation/adaptation goals. An initial phase might focus on building confidence, capabilities and national strategies, during which capacity building, technical assistance and financial incentives would be supported by public funds, possibly from a Multidonor Trust Fund using proceeds from auctioning allowances. Eventually emission reductions (ERs) generated from pilot projects could be purchased. Such ERs would not be used for compliance, but rather to gain experience and indicate to farmers that environmental services can be financially rewarded. An intermediate phase might begin implementation of strategies, up-scaling projects and, where nationally appropriate, sectoral mitigation approaches using public funding and simple methodologies (e.g. Tier 1). Developing countries, which have or acquire capacity and knowledge could transition to progressively greater quantification of emissions reductions, utilization of incentives from market mechanisms, and implementation of more robust MRV methodologies with ex-ante safeguards to ensure social and environmental integrity. This in turn might open the door to a NAMA carbon trading mechanism for emission reductions/removals. This could help to leverage private sector investment and innovation capacity and could possibly lead to the eventual development of national cap and trade systems, where deemed to be nationally appropriate.

#### **4.3 Measuring, Reporting and Verification (MRV) requirements – part of a step-wise approach**

Developing agricultural MRV approaches would need to consider purpose, costs and country specific capacity. Countries will require, different transition periods to adopt accurate MRV systems for monitoring emission reductions and removals. Financial assistance, capacity building and technology transfer is required for developing countries to develop MRV systems for agricultural mitigation activities. Higher accuracy is expected for offsetting through market based approaches. A step-wise approach with agreed increasing accuracy thresholds might be best suited to enable learning by doing and to encourage urgently required early mitigation actions. As noted in Chapter 3, one of the most important steps needed to build confidence in MRV systems for terrestrial mitigation from agriculture is the establishment of a high-quality network of soil benchmark monitoring sites.

## 4.4 Conclusions

An immediate learning and confidence building process for all stakeholders in the agricultural sector could help to build commitment for actions on agricultural mitigation. Steps to achieve international and national levels of confidence outlined in this chapter include:

- High level political support for synergistic action on food security and climate change as part of the outcome of the COP15 in Copenhagen, including an agreement to provide a mandate to SBSTA to work on methodological issues and possible parameters for agricultural mitigation.
- Agricultural mitigation actions need to be placed in national development strategies and tailored to country specific circumstances. This may be achieved through a process of prioritization based upon the potential of agricultural mitigation actions to generate synergies with adaptation and food security, as well as their associated implementation and MRV costs and national institutional capacity.
- Differing national capacities and circumstances indicate that phased approaches will be needed to build required confidence, capacity and experience at the country level. Adequate and sustainable financing to support a phased implementation approach at national level would be required.

# 5

## Conclusions and recommendations

This paper has explored the potential synergies and trade-offs between food security, adaptation and climate change mitigation from agricultural practices in developing countries, indicating promising mitigation options, options for their financing, and possible elements in designing country implementation processes. It is intended to stimulate dialogue among policy makers involved in the UNFCCC COP15 (Copenhagen, December 2009), those involved in policy formulation at national level, and more generally those that see sustainable agriculture policies and practices as part of the solution to addressing climate change and food insecurity across the developing world. In so doing, it has sought to initiate a process to clarify some of the key choices and steps involved in enabling and designing country-led and country-specific implementation processes.

### Main conclusions

#### **Synergies and trade-offs between agricultural mitigation and food security**

- A wide range of agricultural investment options can improve food security, increase the adaptive capacity of the food system to respond to climate change, and contribute to mitigation. Others may involve difficult trade-offs, some of which can be managed.
- A more holistic vision of food security, agricultural mitigation, adaptation and development is needed if synergies are to be maximized and trade-offs minimized. This needs to be mainstreamed into global agendas and national strategies for addressing climate change and food security.
- Synergies between food security and agricultural mitigation are mostly found in strategies for agricultural intensification and for increased resilience of the food production system, while trade-offs tend to occur with changed land use.
- Realizing the synergies and minimizing trade-offs between agricultural mitigation and food security will require financing that values such synergies and combines new and additional climate financing with ODA.
- Further research is needed to identify locations and conditions where food security adaptation and mitigation benefits intersect in a cost-effective way.

#### **Enabling action on food security and climate change mitigation: financing options**

- Structured and phased financing are crucial in enabling actions to capture the synergies between agricultural development, food security and agricultural mitigation in developing countries.
- Given the size of overall agricultural investment requirements versus the magnitude of potential financial flows for terrestrial based mitigation in the agricultural sector, leveraging finance from mitigation to support climate smart agricultural development strategies that support food security, adaptation and mitigation will be most effective for capturing synergies.
- Both direct and facilitating financing is needed to enable mitigation action. The former can cover capacity building, investment, and operating costs associated with mitigation actions, while the latter

can support the creation of frameworks and institutions that enable and incentivize financing from other public and private financing sources.

- National ownership in the design and implementation of NAMAs is critical for their success. Mitigation actions that have synergies with the national development processes will be more likely to succeed.
- There is currently no consensus on MRV for financing mechanisms, but decisions in this regard would affect the costs and viability of different agricultural mitigation activities. Making any eventual MRV system operational would require a phased approach tailored to country specific agricultural conditions and capabilities using pilot approaches and capacity building to build confidence and expertise.

### **Moving from negotiations to implementation: options for action**

An immediate learning and confidence building process for all stakeholders in the agricultural sector could help to build commitment for actions on agricultural mitigation. Specific steps to achieve international and national levels of confidence outlined in this chapter include:

- High level political support for possible next steps should form part of the outcome of the COP15 in Copenhagen, including an agreement to provide a mandate to SBSTA to work on methodological issues and possible parameters for international/national frameworks for implementation.
- Agricultural mitigation actions need to be embedded in national development strategies and tailored to country specific circumstances. This may be achieved through a process of prioritization based on the potential of agricultural mitigation actions to generate synergies with adaptation and food security, as well as their associated implementation and MRV costs and national institutional capacity.
- Differing national capacities and circumstances indicate that phased approaches will be needed to build required confidence, capacity and experience at the country level. Adequate and sustainable financing to support a phased implementation approach at national level would be required.

### **Main recommendations**

- (1) Capturing synergies and managing trade-offs between food security and agricultural mitigation can be part of the solution to these two challenges and this should be reflected in the outcome reached at the United Nations Climate Change Convention (UNFCCC) Conference of the Parties (COP15) in Copenhagen.
- (2) The formulation and implementation of climate change and food security strategies will benefit from greater awareness of the potential synergies and trade-offs between these two policy areas within the agriculture sector, and how they might be best managed to generate multiple benefits rather than perverse outcomes.
- (3) Capturing the potential of agricultural mitigation and its co-benefits will require new and additional resources, multiple funding streams, innovative and flexible forms of financing, and the unequivocal eligibility of agriculture, including soil carbon sequestration, in existing and any new financing mechanisms.
- (4) Beyond Copenhagen, possible next steps that Parties may wish to consider, include:
  - (i) A work programme on agriculture initiated within the UNFCCC Subsidiary Body for Scientific and Technological Advice (SBSTA), with technical support provided, inter alia, through already

ongoing Intergovernmental Panel on Climate Change (IPCC) - FAO cooperation. Such a work programme could address methodological issues, including those related to reference levels, financing, and MRV. A decision in this regard could be taken by the UNFCCC COP, at its fifteenth session in Copenhagen.

- (ii) A suite of country-led pilots launched to build readiness, confidence and capacity for implementation of nationally appropriate agricultural mitigation action. The modality of implementation could be a phased approach, linked to country-specific capacities, circumstances and sustainable development processes.

## References

# 6

1. Andriessse, J.P., *Nature and Management of Tropical Peat Soils*, in *FAO soils Bulletin*. 1988.
2. Angelsen, A., Brown S., Loisel C., Peskett L., Streck C., Zarin D., *Reducing Emissions from Deforestation and Forest Degradation (REDD): An Options Assessment Report*. 2009, Meridian Institute.
3. Antle, J.M., Capalbo S.M., Hewitt J., *Testing hypotheses in integrated impact assessments: climate variability and economic adaptation in great plains agriculture in Nebraska Earth Science Education Network*. 1999, National Institute for Global Environmental Change, University of Nebraska-Lincoln: Lincoln, NE, USA. p. T5-4 and 21.
4. Antle, J.M., Capalbo S., Mooney S., Elliott EH., Paustian KH., *Sensitivity of carbon sequestration costs to soil carbon rates*. *Environmental Pollution* 2002. 116(3): p. 413-422.
5. Antle, J.M., Diagana B., *Creating Incentives for the Adoption of Sustainable Agricultural Practices in Developing Countries: The Role of Soil Carbon Se-questration* *American Journal of Agricultural Economics*, 2003. 85(5): p. 1178-1184.
6. Antle, J.M., S. M. Capalbo, S. Mooney, E. Elliott and K. Paustian, *Spatial Heterogeneity, contract design and the efficiency of carbon sequestration policies for agriculture* *Journal of Environmental Economics Mangement*, 2003. 46: p. 231-250.
7. Antle, J.M., Stoorvogel J.J. , Valdivia R.O. , *Assessing the Economic Impacts of Agricultural Carbon Sequestration: Terraces and Agroforestry in the Peruvian Andes*. *Agriculture, Ecosystems and Environment* 2007. 122(4): p. 435-445.
8. Antle, J.M., Stoorvogel, J.J., *Agricultural Carbon Sequestration, Poverty and Sustainability*. *Environment and Development Economics*, 2008. 13(3): p. 327-352.
9. Barrett, C.B., Place F., Aboud A.A., ed. *Natural Resources Management in African Agriculture: Understanding and Improving Current Practices*. 2002, CAB International.
10. Baudeon, F., Mwanza H.M., Triomphe B., Bwalya M. , *Conservation agriculture in Zambia: a case study of Southern Province*. 2007, African Conservation Tillage Network, Centre de Coopération Internationale de Recherche Agronomique pour le Développement, FAO: Nairobi.
11. Bellassen, V., Manlay R., Chéry J.P., Gitz V., Touré A., Bernoux M., Chotte J.L. , *Multicriteria spatialization of soil organic carbon sequestration potential from agricultural intensification in Senegal*. *Climatic Change*, 2009.
12. Bockel, L., Smith B., *Climate Change and Agriculture Policies: how to mainstream climate change adaptation and mitigation into agriculture policies?*, in *EASYPOL 2009* FAO: Rome.
13. Breidenich, C., Bodansky D., *Measurement, Reporting and Verification in a posts-2012 climate agreement*. 2009, PEW Centre on Global Climate Change.
14. Brown, D.J., K.D. Shepard, M.G. Walsh, M.D. Mays and T.G. Reinsch, *Global soil characterization with VNIR diffuse reflectance spectrometry*. *Geoderma*, 2006. 132: p. 273-290.
15. Bruinsma, J., *The Resource Outlook to 2050*, in *Expert Meeting on "How to Feed the World in 2050"* 2009: FAO, Rome
16. Caldeira, K., G. Morgan, D. Baldocchi, P. Brewer, C.T.A. Chen, G.-J. Nabuurs, N. Nakicenovic, G.P. Robertson, *A portfolio of carbon management options*, in *Towards CO<sub>2</sub> stabilization*, C.B. Field, Editor. 2004, Island Press: New York.
17. CAST, *Climate Change and Greenhouse Gas Mitigation:Challenges and Opportunities for Agriculture*. 2004, Council for Agricultural Science and Technology: Ames, IA. p. pp.120.
18. ClimSoil, *Review of existing information on the interrelations between soil and climate change in the EU member states*. 2008.
19. Cline, W.R., *Global Warming and Agriculture: Impact Estimates by Country*. 2007, Center for Global Development and Peterson Institute for International Economics: Washington, D.C.
20. Coleman, K., Jenkinson DS, *RothC-26.3. A model for the turnover of carbon in soil*, in *Evaluation of soil organic matter models using existing, long-term data-sets* D. Powlson, Smith P, Smith JU, Editor. 1996, Springer: Berlin Heidelberg New York. p. pp 237-246.
21. Conant, R.T., Paustian K., *Spatial variability of soil organic carbon in grass-lands: implications for detecting change at different scales* *Environmental Pollution* 2002. 116: p. 127-135.
22. Conant, R.T., G.R. Smith and K. Paustian, *Spatial variability of soil carbon in forested and cultivated sites: Implications for change detection* *Journal of Environmental Quality*, 2003. 32: p. 278-286.
23. Conant, R.T., M. Easter, K. Paustian, A. Swan, S. Williams., *Impacts of periodic tillage on soil C stocks: A synthesis*. *Soil and Tillage Research* 2007. 95: p. 1-10.

24. Daughtry, C.S.T., P.C. Doraiswamy, E.R. Hunt Jr., A.J. Stern, J.E. McMurtrey III, J.H. Prueger, *Remote sensing of crop residue cover and soil tillage intensity*. Soil and Tillage Research, 2006. 91: p. 101-108.
25. Del Grosso, S.J., W.J. Parton, A.R. Mosier, M.K. Walsh, D.S. Ojima, P.E. Thornton, *DAYCENT national-scale simulations of nitrous oxide emissions from cropped soils in the United States*. Journal of Environmental Quality, 2006. 35: p. 1451-1460.
26. Dutilly-Diane, C., Sadoulet E., de Janvry A., *How Improved Natural Resource Management in Agriculture Promotes the Livestock Economy in the Sahel*. Journal of African Economies, 2003. 12: p. 343-370.
27. EC, *Stepping up international climate finance: A European blueprint for the Copenhagen deal*. 2009.
28. Ellis, J., Moarif, S., *GHG Mitigation Actions: MRV Issues and Options*. 2009, OECD
29. EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006*. 2008, Office of Atmospheric Programs: Washington, D.C. .
30. EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2007*. 2009, Office of Atmospheric Programs.
31. Evans, A., *The Feeding of the Nine Billion. Global Food Security for the 21st Century*. 2009, Chatman House.
32. FAO. *Rome Declaration on World Food Security and World Food Summit Plan of Action. in World Food Summit 13-17 November 1996*. 1996. Rome.
33. FAO, *The State of Food Insecurity in the World 2001*. 2002: Rome.
34. FAO, *World Agriculture: towards 2030/2050. Interim report*. 2006: Rome.
35. FAO, *The State of Food and Agriculture. Paying Farmers for Environmental Services*. 2007, FAO: Rome.
36. FAO, *Food Outlook: Global Market Analysis*. 2008 a: Rome.
37. FAO, *Financing climate change adaptation and mitigation in the agriculture and forestry sectors, in UNFCCC Submission by the Food and Agriculture Organization (FAO) and the International Fund for Agricultural Development (IFAD)*. 2008 b: Rome.
38. FAO, *The State of Food Insecurity in the World 2008*. 2008 c: Rome
39. FAO, *Climate Change and Food Security: A Framework Document*. 2008 d: Rome.
40. FAO, *Enabling agriculture to contribute to climate change mitigation, in UNFCCC Submission by the Food and Agriculture Organization (FAO)*. 2009 a: Rome.
41. FAO, *Anchoring Agriculture within a Copenhagen Agreement, in A policy brief for UNFCCC parties by FAO*. 2009 b: Rome.
42. FIBL, *Organic Farming and Climate Change, in Technical paper for International Trade Centre UNCTAD/WT*. 2008, Research Institute of Organic Agriculture: Geneva.
43. Fischer, G., Shah M., van Velthuizen H., *Climate Change and Agricultural Vulnerability, in Contribution to the World Summit on Sustainable Development, Johannesburg 2002*. 2002, International Institute for Applied Systems Analysis (IIASA): Laxenburg.
44. Fischer, G., Tubiello FN, van-Velthuizen H, Wiberg DA, *Climate Change Impacts on Irrigation Water Requirements: Effects of Mitigation 1990–2080 Technological Forecasting and Social Change*, 2007. 74: p. 1083-1107.
45. Follett, R.F., Kimble J.M., Lal R., *The potential of U.S. grazing lands to sequester soil carbon, in The Potential of U.S. Grazing Lands to Sequester Carbon and Mitigate the Greenhouse Effect*, R.F. Follett, Kimble J.M., Lal R., Editor. 2001, Lewis Publishers: Boca Raton, Florida. p. 401-430.
46. Freibauer, A., Rounsevell M., Smith P., Verhagen A., *Carbon sequestration in the agricultural soils of Europe*. Geoderma, 2004. 122: p. 1-23.
47. Garten, C.T., S. D. Wulschleger, *Soil carbon inventories under a bioenergy crop (Switchgrass): Measurement limitations*. Journal of Environmental Quality 1999. 28: p. 1359-1365.
48. Giller, K.E., Witter E., Corbeels M., Tittonell P., *Conservation agriculture and smallholder farming in Africa: The heretics' view*. Field Crops Research, 2009. 114: p. 23-34.
49. Gregory, P., Ingram JSI., Brklacich M., *Climate change and food security* Philosophical Transactions of the Royal Society B, 2005. 360: p. 2139-2148.
50. Howden, S.M., Soussana, J. F., Tubiello, F. N., Chhetri, N., Dunlop, M., Meinke, H., *Adapting agriculture to climate change*. PNAS, 2007. 104: p. 19691-19696.
51. IIASTD, *Agriculture at a Crossroads, in International Assessment of Agricultural Knowledge, Science and Technology for Development*. 2008: Washington, DC.
52. IPCC, *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*. 1996.
53. IPCC, ed. *Climate Change 2001: impacts, adaptation and vulnerability. Report of the working group II*. 2001, Cambridge University Press, UK. pp. 967.
54. IPCC, *Good Practice Guidance for Land Use, Land-Use Change and Forestry*. 2003.

55. IPCC, *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, H. Eggleston, Buendia L, Miwa K, Ngara T, Tanabe K, Editor. 2006, The National Greenhouse Gas Inventories Programme, Intergovernmental Panel on Climate Change
56. IPCC, *Agriculture, in Climate Change 2007: Mitigation*. 2007, Working Group III Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.
57. Janzen, H.H., D.A. Angers, M. Boehm, M. Bolinder, R. L. DeJardins, J.A. Dyer, B.H. Ellert, D.J. Gibb, E.G. Gregorich, B.L. Helgason, R. Lemke, D. Mase, S.M. McGinn, T.A. McAllister, N. Newland, E. Pattey, P. Rochette, W. Smith, A.J. Van-denBygaart, H. Wang, *A proposed approach to estimate and reduce net greenhouse gas emissions from whole farms* Canadian Journal of Soil Science, 2006. 86: p. 401-418.
58. Ju, X.T., Xing G.C., Chen X.P., Zhang S.L., Zhang L.J., Liu X.J., Cui Z.L., Yin B., Christie P., Zhu Z.L., Zhang F.S., *Reducing environmental risk by improving N management in intensive Chinese agricultural systems*. PNAS, 2009. 106: p. 3041-3046.
59. Jung, M.K., Henkel, M. Herold, G. Churkina, *Exploiting synergies of global land cover products for carbon cycle modeling*. Remote Sensing of the Environment, 2006. 101: p. 534-553.
60. Kahn, B.M., Zaks D., *Investing in Agriculture: Far-Reaching Challenge, Significant Opportunity. An Asset Management Perspective*. 2009, DB Climate Change Advisors.
61. Kahrl, F., Roland-Holst D, *China's water-energy nexus*. Water Policy, 2008. 10(S1): p. 51-65.
62. Klein, R.J.T., S. Huq, F. Denton, T.E. Downing, R.G. Richels, J.B. Robinson, F.L. Toth, *Interrelationships between adaptation and mitigation, in Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Editor. 2007, Cambridge University Press: Cambridge, UK. p. 745-777.
63. Kwesiga, F.R., Franzel S., Place F., Phiri D., Simwanza C.P., *Sesbania sesban improved fallows in eastern Zambia: Their inception, development and farmer enthusiasm*. Agroforestry Systems 1999. 47: p. 49-66.
64. Lal, R., *Residue management, conservation tillage and soil restoration for mitigating greenhouse effect by CO<sub>2</sub>-enrichment*. Soil and Tillage Research, 1997. 43: p. 81-107.
65. Lal, R., Bruce J.P., *The potential of world cropland soils to sequester C and mitigate the greenhouse effect*. Environmental Science and Policy, 1999. 2: p. 177-185.
66. Lal, R., *Carbon emissions from farm operations* Environment International 2004a. 30: p. 981- 990.
67. Lal, R., *Soil carbon sequestration to mitigate climate change*. Geoderma, 2004b. 123: p. 1-22.
68. Lal, R., *Climate Change and Food Security Soil Carbon Sequestration Impacts*. Science, 2004c. 304: p. 1623.
69. Lal, R., Cerri C.C., Bernoux M., Etchevers J., Cerri C.E.P., ed. *Carbon Sequestration in Soils of Latin America*. 2006, Food Products Press, The Haworth Press Inc.: Binghamton, NY. 554.
70. Leiva, F.R., Morris, J., and Blackmore, B.S.. *Precision farming techniques for sustainable agriculture. in First European Conference on Precision Agriculture*. 1997. Warwick.
71. Li, C., Aber J, Stange F, Butterbach-Bahl K, Papen H, *A process-oriented model of N<sub>2</sub>O and NO emissions from forest soils: 1. Model development*. Journal of Geo-physical Research 2000. 105: p. 4369-4384.
72. Lipper, L., Dutilly-Diane D., McCarthy N., *Supplying Carbon Sequestration from West African Rangelands: Opportunities and Barriers*. Rangeland Ecology and Management (forthcoming).
73. Lobell, D.B., Burke M.B., Tebaldi C., Mastrandrea M.D., Falcon W.P., Naylor R.L., *Prioritizing climate change adaptation needs for food security in 2030*. Science, 2008. 319(5863): p. 607-610.
74. Lokupitiya, E., K. Paustian, *Agricultural soil greenhouse gas emissions: A review of national inventory methods*. Journal of Environmental Quality, 2006. 35: p. 1413-1427.
75. McCarthy, N., Dutilly-Diane C., Drabo B., Kamara A., Vanderlinden J.P., *Managing Resources in Erratic Environments: An Analysis of Pastoralist Systems in Ethiopia, Niger, and Burkina Faso*. 2004, International Food Policy Research Institute: Washington, DC.
76. McConkey, B., W. Lindwall, *Measuring soil carbon stocks: a system for quantifying and verifying change in soil carbon stocks due to changes in management practices on agricultural land*. 1999, Agriculture and Agri-Food Canada.
77. McKinsey, *Pathways to a low-Carbon Economy*. 2009.
78. McMahon, H., Remi M., *Keeping Track: National Positions and Design Elements of an MRV Framework, in WRI Working Paper*. 2009, World Resources Institute: Washington DC.
79. Mooney, S., J. M. Antle, S. M. Capalbo, K. Paustian, *Influence of project scale and carbon variability on the costs of measuring soil C sequestration*. Environmental Management 2004. 33: p. 252-263.
80. Mooney, S., K. Gerow, J. Antle, S. Capalbo, K. Paustian, *Reducing standard errors by incorporating spatial autocorrelation into a measurement scheme for soil carbon credits* Climatic Change, 2007. 80: p. 55-72.

81. Nair, P.K.R., Buresh R.J., Mugendi D.N., Latt C.R., *Nutrient cycling in tropical agroforestry systems: myths and science*, in *Agroforestry in Sustainable Agricultural Systems*, L.E. Buck, J.P. Lassoie, E.C.M. Fernandes, Editor. 1999, CRC Press: Boca Raton, Florida, USA. p. 1-31.
82. Neuhoff, K., Fankhauser, S., Guerin, E., Hourcade, J.C., Jackson, H., Raja, R., Ward, J., ed. *Structuring international financial support to support domestic climate change mitigation in developing countries* 2009, Climate Strategies.
83. Niles, J.O., Brown S., Pretty J.N., Ball A.S., Fay J., *Potential carbon mitigation and income in developing countries from changes in use and management of agriculture and forest lands*. Philosophical Transactions of the Royal Society of London A, 2002. 360: p. 1621-1639.
84. Nkonya, E., Pender J., Jagger P., Sserunkuuma D., Kaizzi, C., Ssali, H., *Strategies for sustainable land management and poverty reduction in Uganda*, in *Research Report n.133* 2004, International Food Policy Research Institute: Washington, D.C.
85. Nyende, P., Nyakuni, A., Opio J.P., Odogola W., *Conservation agriculture: a Uganda case study*. 2007, African Conservation Tillage Network, Centre de Coopération Internationale de Recherche Agronomique pour le Développement, FAO: Nairobi.
86. OECD, *The Economics of Climate Change Mitigation: Policies and Options for Global Action Beyond 2012*. 2009, OECD.
87. Oelbermann, M., Voroney R.P., Gordon A.M., *Carbon sequestration in tropical and temperate agroforestry systems: a review with examples from Costa Rica and southern Canada*. Agriculture, Ecosystems and Environment 2004. 104: p. 359-377.
88. Ogle, S.M., R.T. Conant, K. Paustian, *Deriving grassland management factors for a carbon accounting method developed by the Intergovernmental Panel on Climate Change*. Environmental Management 2004. 33: p. 474-484.
89. Ogle, S.M., F.J. Breidt, K. Paustian, *Agricultural management impacts on soil organic carbon storage under moist and dry climatic conditions of temperate and tropical regions*. Biogeochemistry, 2005. 72: p. 87-121.
90. Ogle, S.M., F.J. Breidt, K. Paustian, *Bias and variance in model results due to spatial scaling of measurements for parameterization in regional assessments*. Global Change Biology 2006. 12: p. 516:523.
91. Ogle, S.M., F.J. Breidt, M. Easter, S. Williams, K. Killian, K. Paustian. *Scale and uncertainty in modeled soil organic carbon stock changes for U.S. croplands using a process-based model*. Global Change Biology, 2009. (in press).
92. Oldeman, L.R., *The global extent of soil degradation*, in *Soil Resilience and Sustainable Land Use*, D.J. Greenland, Szabolcs, I., Editor. 1994, CAB International: Wallingford, UK. p. 99-118.
93. Osgood, D., *Climate Information, Index Insurance and Climate Risk Management in Food Security and Environmental Change Conference*. 2008: Oxford UK.
94. Otsuka, K., Place F., *Land tenure and natural resource management. A comparative study of agrarian communities in Asia and Africa* 2001, International Food Policy Research Institute: Washington, D.C.
95. Pagiola, S., *Payments for environmental services in Costa Rica* Ecological Economics, 2008. 65(4): p. 712-724.
96. Parry, M.L., O.F. Canziani, J.P. Palutikof, P.J. van der Linden, C.E. Hanson, ed. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. 2007, Cambridge University Press: Cambridge, UK. pp. 391-431.
97. Parton, W., Schimel DS, Cole CV, Ojima DS *Analysis of factors controlling soil organic matter levels in Great Plains grasslands* Soil Science Society of America Journal, 1987. 51: p. 1173-1179.
98. Parton, W., Ojima DS, Cole CV, Schimel DS, *A general model for soil organic matter dynamics: sensitivity to litter chemistry, texture and management in Quantitative modeling of soil forming processes*, R. Bryant, Arnold RW, Editor. 1994, Soil Science Society of America: Madison, WI. p. pp. 147-167.
99. Parton, W.J., S.J. Del Grosso, M.D. Harman, R.E. Martin, A.R. Mosier, D.S. Ojima, D.S. Schimel, *Generalized model for NO<sub>x</sub> and N<sub>2</sub>O emissions from soil*. Journal of Geophysical Research-Atmospheres, 2001. 106: p. 17403-17419.
100. Paul, H., A. Ernstring, S. Semina, S. Gura, A. Lorch *Agriculture and climate change: Real problems, false solutions*. 2009, Eonexus, Biofuelwatch, Grupo de Reflexion Rural and NOAA - Friends of the Earth Denmark.
101. Paustian, K., Collins, H.P., Paul, E.A., *Management controls on soil carbon*, in *Soil Organic Matter in Temperate Agroecosystems: Long-term Experiments in North America*, E.A. Paul, Paustian, K., Elliott, E.T., Cole, C.V., Editor. 1997a, CRC Press: Boca Raton, FL, USA. p. pp. 15-49.
102. Paustian, K., O. Andren, H. Janzen, R. Lal, P. Smith, G. Tian, H. Tiessen, M. van Noordwijk, P. Woormer, *Agricultural soil as a C sink to offset CO<sub>2</sub> emissions*. Soil Use and Management 1997b. 13: p. 230-244.

103. Paustian, K., E.T. Elliott, K. Killian, J. Cipra, G. Bluhm, J.L. Smith., *Modeling and regional assessment of soil carbon: A case study of the Conservation Reserve Program in Soil Management for Enhancing Carbon Sequestration*, R. Lal, K. McSweeney, Editor. 2001, SSSA Special Publ.: Madison, WI. p. pp. 207-225.
104. Paustian, K., J. Brenner, M. Easter, K. Killian, S. Ogle, C. Olson, J. Schuler, R. Vining, S. Williams, *Counting carbon on the farm: Reaping the benefits of carbon offset programs*. Journal of Soil and Water Conservation, 2009. 64: p. 36A-40A
105. Perez, C., Roncoli C., Neely C., Steiner J.L., *Can carbon sequestration markets benefit low-income producers in semi-arid Africa? Potentials and challenges* Agricultural Systems 2007. 94: p. 2-12.
106. Pretty, J., Hine R., *Reducing Food Poverty with Sustainable Agriculture: A Summary of New Evidence, in Final Report of the "SAFE-World"(The Potential of Sustainable Agriculture to feed the World) Research Project*. 2001, University of Essex: Colchester, UK.
107. Pretty, J.N., Morison J.I.L., Hine R.E., *Reducing food poverty by increasing agricultural sustainability in developing countries*. Agriculture, Ecosystems and Environment, 2003. 95: p. 217-234.
108. Pretty, J.N., Noble A.D., Bossio D., Dixon J., Hine R.E., Penning de Vries F.W.T., Morison J.I.L., *Resource-Conserving Agricultural Increases Yields in Developing Countries*. Environmental Science and Technology, 2006. 40.
109. Riedacker, A., *A global land use and biomass approach to reduce greenhouse gas emissions, fossil fuel use and to preserve biodiversity in Fondazione Eni Enrico Mattei working papers*. 2007. p. wp 121.
110. Robertson, G.P., K. M. Klingsmith, M. J. Klug, E. A. Paul, J. R. Crum, B. G. Ellis, *Soil resources, microbial activity, and primary production across an agricultural ecosystem*. Ecol Appl 1997. 7: p. 158-170.
111. Rosenzweig, C., Tubiello F.N., *Adaptation and mitigation strategies in agriculture: an analysis of potential synergies*. Mitigation and Adaptation Strategies for Global Change, 2006. 12: p. 855-873.
112. Sainji, U.M., Whitehead W.F., Singh B.P., *Agricultural Management Practices to sustain Crop Yields and Improve Soil and Environmental Qualities*. The Scientific World Journal, 2003. 3: p. 768-789.
113. Schlesinger, W.H., *Carbon sequestration in soils: some cautions amidst optimism*. Agriculture, Ecosystems and Environment, 2000. 82: p. 121-127.
114. Schmidhuber, J., Tubiello F.N., *Global food security under climate change*. Proceedings National Academy of Science, 2007. 104: p. 19703-19708.
115. Schmidhuber, J., Bruinsma J., Boedecker G., *Capital requirements for agriculture in developing countries to 2050, in Expert Meeting on "How to Feed the World in 2050"* 2009: FAO, Rome.
116. Serbin, G., C.S.T. Daughtry, E. Raymond Hunt Jr., J.B. Reeves III, D.J. Brown, *Effects of soil composition and mineralogy on remote sensing of crop residue cover*. Remote Sensing of Environment 2009. 113 p. 224-238.
117. Shepard, K.D., M.G. Walsh, *Development of reflectance spectral libraries for characterization of soil properties* Soil Science Society of America Journal, 2002. 66 (3): p. 988 - 998.
118. Smith, G.R., B. A. McCarl, C. Li, J. H. Reynolds, R. Hammerschlag, R. L. Sass, W.J. Parton, S. M. Ogle, K. Paustian, J. Holtkamp, W. Barbour, ed. *Harnessing farms and forests in the low-carbon economy: how to create, measure, and verify greenhouse gas offsets*. 2007, Duke University Press, Nicholas Institute for Environmental Policy Solutions: Raleigh, NC. pp. 229.
119. Smith, P., *How long before a change in soil organic carbon can be detected?*. Global Change Biology 2004. 10: p. 1878-1883.
120. Smith, P., D. Martino, Z. Cai, D. Gwary, H.H. Janzen, P. Kumar, B. McCarl, S. Ogle, F. O'Mara, C. Rice, R.J. Scholes, O. Sirotenko, M. Howden, T. McAl-lister, G. Pan, V. Romanenkov, U. Schneider, S. Towprayoon, M. Wattenbach, and J.U. Smith, *Greenhouse gas mitigation in agriculture*. Philosophical Transactions of the Royal Society B, 2008. 363(1492): p. 789-813.
121. Stern, N., ed. *Stern Review: Economics of Climate Change*. 2006, Cambridge University Press: Cambridge. 712.
122. Sullivan, D.G., J.N. Shaw, D. Rickman, P.L. Mask, J.C. Luvall, *Using remote sensing data to evaluate surface soil properties in Alabama Ultisols*. Soil Science 2005. 170: p. 954-968.
123. Tennigkeit, T., Wilkes, A., *An Assessment of the Potential for Carbon Finance in Rangelands in ICRAF Working Papers*. 2008, ICRAF.
123. UN, *World Population Prospects: The 2008 Revision*. 2009, United Nations Population Division: New York.
125. UNEP, *Global green new deal, in Policy brief*. 2009.
126. UNFCCC, *Challenges and opportunities for mitigation in the agricultural sector, in Technical paper: FCCC/TP/2008/8*. 2008.

127. United States Climate Change Science Program, *The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity in the United States*. 2009, Final report of Synthesis and Assessment Product 4.3.
128. Verchot, L.V., Van Noordwijk M., Kandji S., Tomich T., Ong C., Albrecht A., Mackensen J., Bantilan C., Anupama K.V., Palm C., *Climate Change: Linking adaptation and mitigation through agroforestry* Mitigation and Adaptation Strategies for Global Change, 2007. 12: p. 901-918.
129. Walcott, J., Bruce, S., Sims, J., *Soil carbon for carbon sequestration and trading: a review of issues for agriculture and forestry* 2009, Bureau of Rural Sciences, Department of Agriculture Fisheries & Forestry: Canberra.
130. WB, *Agriculture for Development: World Development Report 2008*. 2007, The World Bank: Washington, DC.
131. WB, *Development and Climate Change: World Development Report 2010*. 2009, The World Bank: Washington, DC.
132. WBGU, Solving the climate dilemma: The budget approach, in Special Report. 2009, WBGU (German Advisory Council on Global Change): Berlin.
133. West, T.O., W.M. Post, *Soil organic carbon sequestration rates by tillage and crop rotation: a global analysis*. Soil Science Society of America Journal 2002. 66: p. 1930-1946.
134. Westman, C.J., J. Hytonen, A. Wall., *Loss-on-ignition in the determination of pools of organic carbon in soils of forests and afforested arable fields*. Communications in Soil Science and Plant Analysis, 2006. 37: p. 1059-1075.
135. Wocat, *Where the Land is Greener – Case Studies and Analysis of Soil and Water Conservation Initiatives Worldwide*, H. Liniger, Critchley W., Editor. 2007, World Overview of Conservation Approaches and Technologies.
136. Wright, A.L., Y. Wang, K.R. Reddy, *Loss-on-ignition method to assess soil organic carbon in calcareous Everglades wetlands* Communications in Soil Science and Plant Analysis, 2008. 39: p. 3074-3083.
137. Wunder, S., *Are direct payments for environmental services spelling doom for sustainable forest management in the tropics?*. Ecology and Society 2006. 11(2): p. 23.
138. Yadav, V., G. Malanson, *Progress in soil organic matter research: litter decomposition, modeling, monitoring and sequestration*. Progress in Physical Geography 2007. 31: p. 131-154.

7.1	Synergies and trade-offs between agricultural mitigation and food security	52
7.2	Measuring, Reporting and Verification (MRV) requirements for agricultural mitigation	56
7.3	Ex-Ante Tool to assess mitigation benefits of investment projects	69
7.4	External implications of domestic agricultural mitigation policy	72
7.5	FAO sources of data relevant for measuring, reporting and verification (MRV) of agricultural mitigation	74
7.6	Use of spatially referenced tools to map the opportunities for mitigation: a FAO example from The State of Food and Agriculture (SOFA)	75
7.7	Technical background paper on Nationally Appropriate Mitigation Actions (NAMAs) for developing countries in the context of agricultural land management	77

## 7.1 Synergies and trade-offs between agricultural mitigation and food security

Practices	Impacts on Food Production	
	Positive	Negative
<b>1. Improved cropland management</b>		
<b>1.1 Improved agronomic practices</b>		
Use of cover crops	Higher yields due to reduced on-farm erosion and reduced nutrient leaching  E.g. Mucuna (velvet bean) cover crop: maize yield from 1.3 to 3-4t/ha without N fertilizer in Benin	May conflict with using cropland for grazing in mixed crop-livestock systems
Improved crop/fallow rotations	Higher yields when cropped, due to increased soil fertility	Reduced cropping intensity may compromise household food security in short-run
Improved crop varieties	Generally increased crop yield  E.g. introduction of new varieties of crops (vegetables) and trees (fruit and forest) increases 60% crop yields in Ethiopia	
Use of legumes in crop rotation	Higher yields due to increased N in soil  E.g. bean and groundnuts yields doubled from 300 to 600 Kg/ha in Kenya)	Reduced cropping intensity may compromise household food security in short-run
<b>1.2 Integrated nutrient management</b>		
Increased efficiency of N fertilizer; organic fertilization; legumes and green manure; compost; animal manure	Higher yields through increased soil fertility and more efficient use of N fertilizer  E.g. maize yields from 2 to 4 t/ha in Kenya; millet from 0.3 to 0.6-1 t/ha and groundnut from 0.3 to 0.6-0.9 t/ha in Senegal; coffee yield up to 0.6-1.2 t/ha (+30-50%) in Cuba; potato from 4 to 10-15 t/ha in Bolivia; cereals from 0.4-0.6 to 2-2.5 t/ha in Honduras, Guatemala and Nicaragua	
<b>1.3 Tillage/residue management</b>		
Incorporation of residues	Higher yields through increased soil fertility, increased water holding capacity	Potential trade-off with use as animal feed
Reduced/zero tillage	Higher yields over long run, particularly where increased soil moisture is valuable  E.g. maize +34% (from 2 to 3.5-4 t/ha) and soya + 11% to 2.47 t/ha in Argentina; maize +67% (from 3 to 5t/ha) in 10 yrs and soya +68% (from 2.8 to 4.7 t/ha) in Brazil (Paraná and Rio Grande do Sul); maize + 47% (to 3.7 t/ha), soya +83% (to 2.7 t/ha), wheat +82% (to 2.1 t/ha) in Brazil (Santa Caterina)	May have limited impacts on yields in short-term; weed management becomes very important; less valuable where waterlogging is a problem
<b>1.4 Water management</b>		
Irrigation	Higher yields, greater intensity of land use	
Bunds/zai	Higher yields, particularly where increased soil moisture is key constraint	Potentially lower yields when extremely high rainfall
Terraces, contour farming	Higher yields due to reduced soil and water erosion, increased soil quality  E.g. maize + 15-25% in the Philippines; millet from 150-300 kg/ha to 400 (poor rainfall) and 700-1000 (good rainfall) kg/ha, in Burkina Faso; millet from 130 to 480 kg/ha in Niger; grass strips improved yields by 50-200% to 0.45-0.925 t/ha in India	May displace at least some cropland

**Impacts on Yield Variability and Exposure to Extreme Weather Events**

Positive	Negative
Reduced variability due to increased soil fertility, water holding capacity	
Reduced variability due to increased soil fertility, water holding capacity	
Reduced variability where varieties are developed for resilience; greater diversity of seed varieties should reduce variability at the local/sub-national level	
Lower variability more likely where good drainage and drought infrequent; experience can reduce farm-level variability over time	Potentially greater variability with frequent droughts
Reduced variability due to increased soil fertility, water holding capacity	
Reduced variability due to reduced erosion and improved soil structure, increased soil fertility, better pest control and improved water retention	
Reduced variability in well-functioning systems	
Reduced variability in dry areas with low likelihood of floods and/or good soil drainage	May increase damage due to heavy rains, when constructed to increase soil moisture
	Reduced variability due to improved soil quality and rainwater management

## Practices

## Impacts on Food Production

	Positive	Negative
Water harvesting (e.g. run-off collection techniques, water storage tank construction, devices for lifting and conveying water)	Higher yields  E.g. cereal +100% in Zimbabwe; basic grain (rice, wheat, pigeon peas, millet and sorghum) from 0.4 to 0.8-1 t/ha in India; wheat +40% (from 3 to 4.2 t/ha), spring maize + 38% (from 6 to 8.3 t/ha) in China	

### 1.5 Perennials and Agroforestry

Live barriers/fences	Higher yields	Reduced arable land
Various agroforestry practices: undersowing of <i>Tephrosia vogelii</i> , pigeon pea and <i>Sesbania sesban</i> in maize for soil fertility improvement; dispersed tree interplanting (e.g. <i>Faidherbia</i> , <i>Acacia polycantha</i> , <i>A.galpinii</i> . + contour grass hedges)	Potentially greater food production, particularly if undertaken on marginal/less productive land within the cropping system. Greater yields on adjacent croplands from reduced erosion in medium-long term, better rainwater management  E.g.: maize from 0.7 to 1.5-2 t/ha in Malawi	Potentially less food, at least in short-term, if displaces intensive cropping patterns

## 2. Improved pasture and grazing management

### 2.1 Improved pasture management

Improving forage quality and quantity	Higher livestock yields due to more and higher quality forage	
Seeding fodder grasses	Higher livestock yields due to greater forage availability	
Improving vegetation community structure (e.g. seeding fodder grasses or legumes; reducing fuel load by vegetation management)	Greater forage/fodder in medium-long term, improvements in forage quality	May reduce forage/fodder in short-term

### 2.2 Improved grazing management

Stocking rate management	Potential increased returns per unit of livestock	Returns at the herd level may decline, at least in the short term
Rotational grazing	Higher livestock yields due to greater forage availability and potentially greater forage quality	Short-term losses likely if rotational system supports fewer head of livestock

## 3. Restoring degraded land

Re-vegetation	Improved yields when crops are sown in the medium-long run; improved yields on adjacent crop or grassland due to reduced wind, soil and/or water erosion	
Applying nutrient amendments (manures, bio-solids, compost)	Improved yields when crops are sown in the medium-long run	

### Impacts on Yield Variability and Exposure to Extreme Weather Events

Positive	Negative
Reduced variability	
Reduced variability of agroforestry products; also likely reduced variability of crops due to improved soil fertility and structure, and greater water holding capacity	
Reduced variability where improved forage is adapted to local conditions	Potentially increased variability where improved forage is more sensitive to climate conditions than natural pasture
Reduced variability where seeded fodder is adapted to local conditions	Potentially increased variability where improved seeded fodder is more sensitive to climate conditions than natural pasture
Reduced variability due to improved soil structure, reduced erosion	
Potentially lower variability in long-term, where forage availability is key factor in livestock output variability	
Potentially lower variability in long-term, where forage availability is key factor in livestock output variability	
Reduced variability in local landscape due to reduced wind, soil, and/or water erosion	

Sources: Antle et al. 2007, Baudeau et al. 2007, Dutilly-Diane et al. 2003, FAO 2007, Freibauer et al. 2004, Giller et al. 2009, Kwesiga et al. 1999, Lal 2004, Niles et al. 2002, Nyende et al. 2007, Pretty and Hine 2001, Pretty et al. 2003, Pretty et al. 2006, Rosenzweig and Tubiello 2006, Smith et al. 2008, Verchot et al. 2007.

## 7.2 Monitoring, Reporting and Verification (MRV) requirements for agricultural mitigation

### 7.2.1 Background

Currently discussed options for measuring, reporting and verifying (MRV) approaches for national agricultural GHG inventories are presented here, together with an overview on existing soil carbon measurement and quantification approaches.

### 7.2.2 MRV for National agricultural GHG inventories

A national GHG inventory is required to monitor the impact of the collaborative mitigation action in the framework of internationally supported NAMAs. The IPCC Good Practice Guidelines (2003) for land use, land-use change and forestry (LULUCF) published detailed GHG inventory and monitoring guidelines for all land-based emissions and removals.

National GHG inventories in Annex I countries are currently stratified by six land-use categories (i.e. Forest Land, Cropland, Grassland, Wetlands, Settlements, and Other Land), subdivided into land remaining in the same category and land converted from one category to another (IPCC, 2006). The land-use categories are designed to enable inclusion of all managed land area within a country. Broad categories of management activities are considered within each land categories. Additional guidance is provided for some specific activities (e.g. methane emissions from paddy fields, GHG emissions from livestock) or for use of aggregated data at national level (e.g. N-fertilizers consumption, liming).

Reporting and verification requirements are detailed in the Kyoto protocol and in communications arising from the follow-up meetings of the Conference of the Parties (COP) for Annex I and non-Annex I countries<sup>1</sup>.

Monitoring guidance from IPCC provides information on the:

- choice of estimation method, considering Tier 1, Tier 2 and Tier 3 approaches;
- choice of activity data;
- uncertainty assessment;
- time series management, quality assurance and quality control procedures; and
- data and information to be documented and archived.

National soil GHG inventories based on Tier 1 approaches require quantitative information on land use, management and climate and soils distribution in order to predict C stock changes related to land use change and the adoption of certain management activities. Default values for C stocks and stock change factors, for specific land use and management options (i.e. activity-based default values) are provided by IPCC (2006). Moving from Tier 1 to Tier 2 requires country-specific estimates of C stocks, stock change factors and emission factors. Usually more detailed information on land use and management is used for Tier 2 approaches. Tier 3 approaches require the most detailed environmental and land use and management data. In addition, Tier 3 estimates require systematic long-term field studies and/or permanent monitoring networks to develop region-specific data and model-based estimates of C stocks and stock changes<sup>2</sup>. National agricultural research and statistical institutions require long-term funding

---

<sup>1</sup> [http://unfccc.int/national\\_reports/items/1408.php](http://unfccc.int/national_reports/items/1408.php)

and technical support to establish and maintain such systems.

Several Annex I countries where agricultural soils are a key source category have implemented, or are in the process of implementing, Tier 2 and 3 level approaches. In contrast, few non-Annex I countries have prepared soil C or N<sub>2</sub>O inventories. In most cases, available data, e.g. through FAO and in-country sources, are sufficient for Tier 1 estimates but capacity and resources for compiling and analyzing the information is the main limiting factor. The FAO farming systems classification and a defined set of management activities along the categories proposed in chapter 2 would be one option to establish a consistent monitoring framework, in particular for global integrated remote sensing and field inventory monitoring approaches.

For higher tiered approaches, additional data collection and research capacity is needed beyond what currently exists in most non-Annex I countries.<sup>3</sup> In Table 7.2.1 the basic differences between the different tier approaches are summarized for mineral and organic soils.

For all the different tier approaches, uncertainty ranges have to be quantified for the specific source category and for the inventory as a whole. Research can contribute to reduce uncertainties over time but, depending on the country capacity, different uncertainty levels have to be accepted.

Reporting is mandatory for Annex I and non-Annex I countries according to Article 12 of the Convention. However, the frequency of submissions, and information required vary (Breidenich and Bodansky 2009). Annex I countries have to submit detailed national GHG inventory reports annually, including emissions from the land-based sector that are reviewed by an expert panel<sup>4</sup>. Annex I countries must use the LULUCF Guidelines published in 2003 for reporting annual GHG inventories under the Convention due in 2005 and beyond (Decision at COP9 in 2003).

Non-Annex I countries are not required to report annually, but they have to provide emissions for the year 1994 in their first submission. For the second national communication, the inventory year to be reported is 2000. The least developed country Parties could estimate their national GHG inventories for years at their discretion. Non-Annex I countries should use the Revised 1996 IPCC Guidelines for National GHG

**Table 7.2.1. IPCC guidance on data requirements and estimation methods**

Soil carbon pool	Tier 1	Tier 2	Tier 3
Organic carbon in mineral soils	Land use and management distribution by climate and soil type. Default reference C stocks and stock change factors from IPCC	Land use and management distribution by climate and soil type. Country-specific data on reference C stocks and stock change factors. Detailed geospatial data on land use and management	Validated model and/or direct measures of stock change through monitoring networks
Organic carbon in organic soils	Area distribution and land use of organic soils. Default emission factors from IPCC	Area distribution and land use and management of organic soils. Country-specific data on emission factors	Area distribution and land use and management of organic soils. Validated process model and/or direct measures of emissions from organic soils

Source: modified from Angelsen et al. 2009

2 Global Soil Change by Promoting long-term Soil-ecosystem Studies, <http://ltse.env.duke.edu/>

3 However, many of the larger non-Annex I countries (e.g. Brazil, China, India, Mexico) have the scientific infrastructure to support higher tier inventory approaches.

4 [http://unfccc.int/national\\_reports/annex\\_i\\_natcom/submitted\\_natcom/items/3625.php](http://unfccc.int/national_reports/annex_i_natcom/submitted_natcom/items/3625.php)

Inventories. There is no mandatory independent quality review. Usually reporting is submitted together with the national communication at unpredictable intervals. As a result many large-scale emitters in developing countries have not submitted reliable and recent data on land-use related emissions. This makes it difficult to complete global emission inventories or to define baselines describing the estimated emissions in business as usual agricultural development scenarios.

FAO is tracking different proxies for land-based GHG emissions in all developing countries through their national census reports, agricultural statistics (see FAOSTAT) and sub-national reporting frameworks<sup>5</sup>. However, this resource intensive work ultimately relies on the data quality provided by national government agencies. Global remote sensing based monitoring systems are providing useful and often complementary information, but also rely on field data to interpret the different signals and to provide good proxies.

Against this background, it would be desirable to have a more consistent land-based GHG inventory for all countries to predict better global climate change and to monitor the impact of mitigation and adaptation actions. International support should be provided, based on country-specific capacity and the global significance of country emissions. As a starting point to improve GHG inventory systems, IPCC equivalent reporting standards could be adopted in a phased approach. Presuming that predominantly agriculture-based economies may choose agriculture as NAMAs, support for knowledge transfer and capacity building for Ministries of Agriculture is urgently required to enable these countries to build capacity for developing baselines and monitoring systems that must be in place before internationally supported and recognized mitigation actions can be implemented.

### **7.2.3 Principal MRV approaches: leakage, permanence, additionality and baselines**

All agricultural GHG accounting methodologies have to consider leakage and permanence. For crediting, the baselines and additionality of the mitigation action has to be demonstrated.

#### **Leakage**

Mitigation actions have to be designed in a way that emission reductions or removals within a defined monitoring boundary do not cause an increase in emissions outside the accounting reference area due to simply relocating the emissions sources. Increasing the monitoring area will decrease respective leakage risks. Therefore, sectoral approaches covering the whole country are preferred. However, if some countries are not adopting mitigation actions or forced to reduce emissions below a pre-defined cap, this can also provide incentives to shift activities outside the country. This international leakage is often linked with trade conflicts because it has an impact on the international competitiveness of a certain sector or sub-sector.

For ex-ante estimates of leakage, some procedures have been developed, e.g. for CDM forest projects, to consider the impact of the project outside the project boundary that are relevant for agricultural mitigation<sup>6</sup>. More empirical estimates would involve monitoring leakage in a pre-defined leakage belt surrounding the boundary of the mitigation action, as discussed in the context of REDD. However, for agricultural practices that substantially maintain or enhance productivity of agricultural goods, leakage would be negligible.

---

<sup>5</sup> [www.fao.org/landandwater/lwris.stm](http://www.fao.org/landandwater/lwris.stm)

## Permanence

Carbon sequestration differs from a permanent GHG emission reduction because: the biosphere's capacity to sequester carbon declines over time, eventually reaching a maximum value as the system finds a new equilibrium; and sequestered carbon is subject to re-emission to atmosphere if mitigation are discontinued.

Options to treat emission reductions, e.g. as temporary certified emission reductions (tCERs), whereby emitters temporarily lease credits and are required to replace them once the temporary credits expire, basically failed. This special unit proved to be not fungible on the market and the liability to replace the temporary credit was unclear. In the EU, tCERs were excluded from the emission trading system. This basically eliminated any demand for offsets from land-based CDM forestry projects in developing countries.

In the meantime alternative mechanisms to ensure the integrity of bio-carbon over a specified duration have been developed, perhaps most notably the Permanence Buffer concept adopted by the Voluntary Carbon Standard (VCS 2008). This approach considers factors affecting the variable risk of loss of permanence for different types of projects/activities to establish a reserve or buffer of sequestered carbon. This has several advantages over other approaches such as discounting. By pooling the permanence risk across a portfolio of projects and taking a conservative approach in ensuring an adequate buffer, soil and biomass C sequestration are fully equivalent to CO<sub>2</sub> emission reductions. Moreover, where adoption of soil and biomass carbon sequestration practices also leads to more sustainable/profitable farming systems, the risk of non-permanence is much lower.

## Additionality

Additionality is important to increase the efficiency of financing mechanisms that aim to reduce emissions or to increase removals. Emission reductions or removals that would occur even in the absence of mitigation finance or targeted climate policies are considered non-additional and should not be supported by mitigation finance. A stepwise approach to demonstrate additionality was proposed by UNFCCC for forestry<sup>7</sup>:

- Step 1. Identification of alternative land use scenarios;
- Step 2. Investment analysis to determine that the proposed project activity is not the most economically or financially attractive of the identified land use scenarios; or
- Step 3. Barriers analysis; and
- Step 4. Common practice analysis.

A similar approach could be used for agricultural mitigation actions. However, at project level the justification of additionality could be replaced by an approved list of agricultural mitigation actions that are eligible in a certain county.

## Baselines and reference scenarios for mitigation actions

Baselines are important reference points to measure the impact of agricultural mitigation actions. Currently options to define baselines are predominantly discussed in the framework of REDD. Considering that land-based accounting may move towards a comprehensive landscape approach (see FAO 2009b), the

---

6 [http://cdm.unfccc.int/methodologies/ARmethodologies/approved\\_ar.html](http://cdm.unfccc.int/methodologies/ARmethodologies/approved_ar.html)

7 <http://cdm.unfccc.int/methodologies/ARmethodologies/tools/ar-am-tool-01-v2.pdf>

terminology introduced in the context of REDD will be used (Angelsen et al. 2009). A BAU baseline describes the emission trajectory assuming no mitigation actions are adopted. A crediting baseline is a politically negotiated baseline, where countries, depending on their common but differentiated responsibility, are rewarded when they stay below the respective level, i.e. BAU baseline minus expected unilateral mitigation actions. In the context of REDD crediting baselines are also referred to as reference levels.

For agriculture it is important to highlight the options related to the spatial delineation of mitigation actions, the parameters to be monitored and the different approaches to establish a baseline.

Estimating baseline scenarios can be simplified if only historic levels are extrapolated. However, this would ignore the country and region specific demand to produce more food to achieve or maintain food security, the impact of climate change and the fact that additional food production should be achieved through efficiency gains while limiting the expansion of agricultural land. Therefore, baseline development models considering the above factors have to be developed.

Under the CDM project, boundaries are basically determined by the capacity of the aggregator to design, monitor and support the implementation of mitigation actions. Inside the project, boundary mitigation actions may be only adopted in certain areas, referred to as activity or adoption areas. Programmatic CDM approaches in the agricultural sector could define regional boundaries along administrative boundaries providing the reference point for respective mitigation actions. Project and programmatic approaches would monitor the adoption of pre-defined project activities. Under a sectoral approach national baselines have to be established and the impact of different mitigation actions such as the adoption of improved technologies or certain policy measures have to be monitored.

## **7.2.4 Land use and efficiency accounting**

### **7.2.4.1 Land-use accounting (emissions per ha)**

Land-based accounting involves measuring carbon stocks and stock changes per unit of land, expressed in tCO<sub>2</sub>e/ha and year. International accounting standards are defined by the IPCC and used by Annex I and some non-Annex I countries in the framework of their national reporting. Land-based accounting approaches have been developed by the IPCC and recognized under the UNFCCC in the framework of national GHG inventories and CDM reforestation and afforestation project based approaches.

Advanced capabilities exist also for implementation of reliable and cost-effective systems for measurement and monitoring of agricultural soil C stock changes and are applied in the framework of the voluntary C market. However, additional investments are needed to develop high-quality systems applicable in developing countries, for both improved national inventories as well as 'project-level' MRV applications. Priority needs are to develop a limited but high-quality network of soil 'benchmark' monitoring sites, develop improved software packages that help integrate geospatial data (climate, soils), management activity data and appropriate soil C estimation models, and to make available remote sensing tools and observations that can be used to quantify key management changes, e.g. land cover change, change in crop types and cropping intensity, crop residue management, for all areas of the globe. The accepted standard of land-based accounting of emissions and removals should be augmented by monitoring and reporting of agricultural commodity production, as a consequence of mitigation practices. Including commodity production as a variable will allow for determination of metrics of emissions per unit of product, which will be useful in assessing and mitigating leakage as well as for combining goals for sustainable agricultural production and food security with GHG reductions.

#### 7.2.4.2 Measurement of soil C stock changes (and N<sub>2</sub>O flux)

Options to quantify soil C stock changes for implementing MRV for agricultural soils include: 1) direct measurements of soil C changes, 2) practice-based approaches using models and 3) a combination of practice-based approaches using models and additional measurements. Attributes of these measurement approaches are detailed below.

##### Direct measurement of soil carbon changes

Estimating the net flux of CO<sub>2</sub> between the atmosphere and soils, which is the variable of interest for GHG mitigation, can in principle be done with direct flux measurements, employing techniques such as eddy-covariance. Emissions of N<sub>2</sub>O are similarly measured as fluxes, typically with chamber methods that measure the N<sub>2</sub>O accumulation in the closed chamber over short time (~10 to 30 min.) intervals, repeatedly during the year. However, these techniques are currently confined to research applications and are not practical for routine soil CO<sub>2</sub> and N<sub>2</sub>O emission estimation for project-scale MRV. For soil C estimation, the net CO<sub>2</sub> exchange between soils and the atmosphere can be estimated by tracking changes in SOC stocks. This approach assumes that the primary C flows that affect SOC stocks are the addition of C from plant/animal residues (which originate with CO<sub>2</sub> uptake by plants) and the losses of CO<sub>2</sub> via decomposition and mineralization of organic matter in the soil. Generally these conditions are met, except where soil erosion rates or leaching of dissolved organic carbon (DOC) are high (the latter condition would be largely restricted to acid forest soils)<sup>8</sup>. Thus measurement of SOC stock changes at the same location at two or more points in time, or measurements of contrasting management treatments (preferably in a randomized field experiment) that have been in place for a known period of time, can be used to estimate net CO<sub>2</sub> emissions or removals by soils.

Well-developed methods exist to measure SOC content and soil bulk density (the two values needed to compute SOC stocks) and have been routinely applied for many decades. Automated dry combustion soil C analyzers are highly accurate and with proper laboratory techniques, the error in estimating SOC contents of a soil sample is small (<< 5% of the mean estimate). These instruments are widely available at universities, research institutes and many private soil testing laboratories around the world, although their availability in many developing countries is limited. Loss-on-ignition (LOI) methods, which measure the reduction in soil mass (due to the loss of organic matter) after combustion in a high-temperature oven, do not require expensive laboratory instruments and thus may be an alternative in some cases. For organic matter-rich litter layers and organic soils, high correlations (>95%) of LOI with C-analyzers have been shown (Wright et al. 2008); however more variable results have been found for mineral soils (Westman et al. 2006) that suggest LOI is not a suitable general measurement method. Diffuse reflectance spectrometry (DRS), usually employing near- and mid-infrared wavelengths, has been proposed as a rapid, low-cost alternative to combustion-based analysis (Shepard and Walsh 2002). Other advantages over conventional laboratory methods include the capability to gather information about other soil properties of interest (e.g. clay mineralogy, cation exchange capacity) (Brown et al. 2006). The main limitation for DRS-based measurements is that current technology requires relatively site-specific calibrations. Because they require conventional lab measurements to develop the calibrations, they may be most applicable, at present, for facilitating re-measurements over time at

---

<sup>8</sup> Inorganic forms of C in soils include dissolved carbonate and bicarbonate ions and solid carbonate minerals. Changes in the inorganic C content of soils also affect the net flux of CO<sub>2</sub> between soils and the atmosphere, however, these fluxes are currently not recognized for C accounting purposes in, for example, the IPCC National GHG Inventory Guidelines, because of the high uncertainties in estimating fluxes with respect to the atmosphere, since carbonates can be mobilized and redeposited in deeper soil layers or in subsurface geological formation, imported through irrigation water, transported in groundwater, etc. Moreover, in most cases changes in inorganic C stocks are much slower than for organic C stocks and thus only organic C stock changes are currently recognized in estimating soil CO<sub>2</sub> emissions and removals.

## BOX

### Soil carbon, nitrate and methane monitoring

Soil C constitutes the largest biotic C stock in nearly all ecosystems (IPCC 2000) and in particular it is the dominant C stock in agricultural systems (cropland and grazing land). Agricultural management can profoundly influence the C balance of the soil in a variety of ways, by affecting the type and amount of organic C added to the soil, as plant residues, manure, composts or other organic amendments, and by affecting the rate of organic matter decomposition, which is controlled by environmental conditions such as temperature and moisture, soil physical and chemical properties and the composition and activity of soil biota. Because the influence of agricultural practices are 'overlain' on the natural processes affecting the soil carbon cycle, rates of soil C gains or losses in response to particular management practices vary considerably – which presents several challenges for quantifying soil C changes.

Emissions of N<sub>2</sub>O are driven primarily by anthropogenic additions of nitrogen (N) to agricultural soils. N<sub>2</sub>O is a product of soil microbial

processes involved in the nitrogen cycle. Several factors interact to determine rates of N<sub>2</sub>O emissions including the amount and form of inorganic N in the soil, soil moisture, temperature, pH, and the amount of easily decomposed organic matter in soil. Consequently, emissions vary greatly both spatially and temporally. The overriding factor controlling emissions is the amount of 'external' N added to the soil (for fertility management), but emissions can be mitigated by adjusting the timing, form and placement of added N and improved irrigation practices.

The primary source of CH<sub>4</sub> from managed soils is rice cultivation – all flooded soils produce methane but rice is the principle crop in which the soil is purposely flooded for long periods of time. Methane emissions are influenced by the duration of flooding, organic matter amendments and the rice variety grown, all of which offer opportunities for management to reduce methane. Livestock are also a major source of agricultural methane emissions.

permanent soil monitoring locations. Soil bulk density is easily measured but requires care in sampling and handling (e.g. avoiding compaction).

Overall, the technology to accurately measure soil C contents exists and is widely available at reasonable cost<sup>9</sup>. Moreover, promising technologies to reduce analysis time and cost, and which are also more easily deployed in locations with limited laboratory infrastructure, are rapidly developing. Thus the challenge in measuring SOC stock changes is not in the measurement technology per se but rather in designing an efficient sampling regime to estimate soil C stocks at field-scales. The spatial variability of SOC is often high (Robertson et al. 1997) and the amount of C present in the soil (i.e. 'background') relative to the change rate is typically high; thus there is a low 'signal-to-noise' ratio. Hence a 5-10 year period between measurements is typically needed to adequately detect the cumulative change (Conant and Paustian 2002, Smith 2004)<sup>10</sup>. Depending on the degree of spatial heterogeneity of SOC and the amount of change relative to the background level, detecting significant changes at field scales can require a relatively large number (e.g. 15-100) of samples (Garten and Wullschlegler 1999). However, sampling designs that incorporate information about the spatial variability (e.g. Mooney et al. 2007) or that use repeated sampling at precisely located monitoring locations (e.g. Conant et al. 2003, Smith et al. 2007) can reduce sample requirements compared to simple random or stratified random sampling designs. Furthermore, since much of variability of soils is expressed at fine spatial scales, sample size requirements, per unit area, decrease greatly as the area of inference increases in size (Conant and Paustian 2002). Thus inclusion of direct measurements in larger aggregated projects or for regional and national scale assessments of SOC are more feasible, in terms of cost per acre, than at the individual farm scale.

## Activity-based soil monitoring approaches

Activity-based approaches build off of field studies and mathematical models of how soil C changes in response to specified changes in land use and management. There is considerable knowledge on the general responses of soils to management and land use change, primarily derived from long-term field experiments. There are a few hundred long-term field experimental sites globally, in which soil C has been measured (for up to several decades) in replicated management treatments consisting of crop rotations, tillage management, fertilizer levels, irrigation and manuring, often with more than one treatment variable in combination. The majority of these are located in temperate regions (e.g. Europe, North America, Australia/New Zealand) but a large number long-term experiments with measurements of soil C also exist in China, India, and South America, but only a few such sites in Africa. A number of reviews, syntheses and meta-analyses of agricultural soil C stock dynamics have been published in recent years (Ogle et al. 2004, 2005; Paustian 1997ab; West and Post 2002), summarizing these data and providing estimates of soil C change for various management practices.

While these experiments constitute an invaluable (and the main) source of empirical data on soil C stock changes, some limitations should be recognized. For example, many of the older experiments were not set up explicitly to study soil C but rather to investigate plant yield responses and/or other metrics. Consequently many do not have initial soil C estimates from the initiation of the experiment and soil measurements have often not been designed to develop a robust time series. Most estimates of soil C change are inferred from differences in soil C stocks between treatments (i.e. relative to the control plots) rather than as time-series estimated differences. Some of the plot sizes are small and thus may suffer some experimental artefacts (e.g. soil movement across plot boundaries). Often they have been located near universities or field stations, often on the favorable sites in the area, and hence they may not be fully representative of the broader agricultural landscape. Soil measurements have often been taken at shallower depths (i.e. 20-30 cm) and deeper measurements (i.e. top 1 m of soil) are relatively sparse. Finally, several regions, particularly in less developed countries, and many management systems, particularly subsistence and low-input systems, are poorly represented.

Despite these limitations, existing data provide an adequate basis to estimate, in most cases, mean rates of change and variability (uncertainty) in soil C stock changes, at regional and national scales, as a consequence of changes in agricultural management practices. Analysis and synthesis of long-term field experimental data are the basis for the IPCC Tier 1 methods for National Greenhouse Gas Inventories (IPCC 2006, Ogle et al. 2004, 2005). Similarly, the higher tier (2 and 3) methods used by several Annex 1 countries (e.g. Australia, Canada, US, UK and several other EU countries) use existing long-term field experimental data as an integral part of their estimation systems. For example, in the US national soil C inventory estimates, a combined approach using observed land use and management statistics, process-based modelling and long-term experiment data, yielded estimates of the average rate of soil C change with a 95% confidence interval of around + 20% of the mean (EPA 2008). However, for finer scale applications, such as project-level accounting, or to estimate year-to-year variation in stock change rates, the uncertainty in the estimates – in the absence of additional data – increases significantly (Ogle et al. 2009).

---

<sup>9</sup> Sample analysis costs for automated CN analyzers in the US are typically in the range of \$3-4/sample. The main costs measurements once samples have been taken from the field is involved in sample preparation, i.e., sieving, drying, grinding, weighing, much of which involves hand labor – hence sample preparation costs are largely determined by local labor costs.

<sup>10</sup> These remeasurement intervals are similar to those used in forest inventories for determination of biomass increment.

Models provide a means to integrate the effects of different land use and management practices, as well as soil and climate effects, on soil C stocks. The models use data on land management practices, i.e. 'activity data', together with information on environmental variables such as climate and soil type, to predict soil C stocks and C stock changes. Thus, models are the central component in activity-based approaches to quantify soil C stock changes, which form the basis for current national-level soil C inventories reported to UNFCCC (Lokupitiya and Paustian 2006). Models and activity-based approaches can also be used in project-level accounting (Antle et al. 2003, Smith et al. 2007). As part of an activity-based system, models provide a means of estimating outcomes (i.e. C stock change) for specified actions (i.e. adoption of prescribed conservation practices), whereby compliance is largely based on monitoring the adoption and maintenance of the prescribed practices. While this does not negate the relevance of including direct measurements of soil C stock changes as a component of verification, activity-based approaches offer several advantages for policy implementation (see below).

Models needed for practice-based approaches can be either empirical models or process-based models. A major advantage of empirical models are their relative simplicity; however, they have some disadvantages in comparison to process-based models which are better able to integrate across a broader range of climate, soil, previous land use and contemporary changes in management practices that determine soil C changes. The main disadvantage to process-based models is that they are generally harder to implement – having been developed primarily as a research tool – and they have not always been well calibrated to use as applied prediction tools. These two classes of models are described below, followed by a description on data sources that support model-based estimates.

The IPCC Tier 1/Tier 2 default methodology is an empirically-based approach that uses a classification of management, soil and climate variables and computes soil C changes for a fixed time interval (20 years is the default time period).

For mineral soils<sup>11</sup>, the default IPCC model estimates the net change in soil C for the top 30 cm of soil over a 20 year time period. The approach could be modified to use a different soil depth or duration if the estimates of stock change factors (see below) were modified accordingly. While the IPCC method was developed primarily to support national inventories, the method (or similar empirically-based methods) can in principle be applied at the project scale if data are available to adequately estimate stock change rates for local conditions (analogous to a Tier 2 approach). In general, the default (Tier 1) factors, which are based on highly aggregated global data sets, would have a high degree of uncertainty if applied at the project scale.

The default methodology uses a set of coefficients (stock change factors) based on soil type, climate, tillage, productivity and other management practices. Climate is divided into nine categories based on average annual temperature, precipitation and, in the tropics, the length of the dry season. Soils are divided into six broad classes based on broadly defined soil properties, including texture, clay mineralogy, morphology, and drainage. Default values for reference C stocks and stock change factors are stratified according to climate and soil type. Reference C stocks represent values found under native, unmanaged ecosystems.

---

<sup>11</sup> Mineral soils do NOT include organic soils, i.e., peat or muck soils, which have very high C contents due to a history of restricted drainage. Cultivated organic soils (after drainage and liming) release C at high rates over an extended time period (many decades) until the organic layer has been largely oxidized. The IPCC inventory methods use a simple emission factor approach (which varies according to land use type and climate) to estimate C emissions from organic soils and none of the process models described model changes in organic soils. In the US cultivated organic soils make up a small fraction of the total agricultural land (< 1Mha) and they mainly occur in Southern Florida, the Sacramento delta and around the Great Lakes.

For a defined parcel of land, the method combines the reference C stock, stock change factors, and information on changes in land use and management. The following equation estimates mineral soil C stock change (IPCC 2006):

$$\Delta SC = (SC_0 - SC_{(0-T)})/D$$

$$SC_i = SC_R * F_{LU} * F_{MG} * F_I * A$$

Where:

- $\Delta SC$  = annual soil carbon stock change, Mg C yr<sup>-1</sup>;
- $SC_0$  = soil organic carbon stock at (current) time of the inventory, Mg C ha<sup>-1</sup>;
- $SC_{(0-T)}$  = SOC stock T years in the past (default is 20 yrs), Mg C ha<sup>-1</sup>;
- A = land area of each parcel, ha;
- $SC_R$  = the reference carbon stock, Mg C ha<sup>-1</sup>;
- $F_{LU}$  = stock change factor for land use type (dimensionless);
- $F_{MG}$  = stock change factor for management/disturbance regime (dimensionless);
- $F_I$  = stock change factor for carbon input level (dimensionless);
- D = Time dependence of stock change factors which is the default time period for transition between equilibrium SOC values (in years). Default is 20 years, but depends on assumptions made in computing the factors  $F_{LU}$ ,  $F_{MG}$  and  $F_I$ . If T exceeds D, use the value for T to obtain an annual rate of change over the inventory time period (0-T years).

For cropland and grazing land, the land use factor (FLU) relates to whether the soil has been in long-term (> 20 yr) annual cropping, grassland (hayland, grazing), set-aside or if land has been converted to/from cropland or grassland in the past 20 years. For cropland, the management factor (FMG) incorporates the effect of different tillage systems. The input factor (FI) relates to management practices that affect the relative amount of C returned to the soil (as plant-derived residues or exogenous additions like animal manure) for a particular land use type. Hence for cropland, it is dependent on the type of crops grown, whether residues are removed or retained, and whether manures are added. For grassland, FI depends on management practices that influence primary productivity, such as fertilization, species improvement and grazing regime. More detailed definitions and default values for stock change factors can be found in the 2006 Guidelines for National Greenhouse Gas Inventories – Volume 4 (IPCC 2006).

The IPCC Tier 1/Tier2 approach is used by several countries (Lokupitiya and Paustian 2006) in their national inventory. Advantages to the system are that it is simple and transparent and can incorporate some of the interactions of multiple management practices on C stock change, as compared to single-practice rate estimates. Disadvantages with the Tier 1 (default) method are that the classification levels for representing climate, soil and management influences are rather coarse and dynamic influences, such as year-to-year climate, are not represented. However, Tier 2 approaches, using locally representative emission factors and more detailed land use and management activity data, can considerably improve estimates. Recently, the ALU greenhouse inventory software tool has been developed for doing Tier 1 and Tier 2 inventories for the AFOLU sector, which includes capabilities to upload spatial data sets, classify land areas, livestock and other emission source categories, as well as providing Quality Assurance/Quality Control (QA/QC) and reporting facilities<sup>12</sup>.

Process-based models include simulation models developed to simulate SOC dynamics in agricultural ecosystems. Several such models have been developed initially for research applications, but increasingly they are being implemented for soil carbon and soil GHG emission estimation, for example,

the Century and DayCent (Parton et al. 1987, 1994, 2001; Del Grosso et al. 2006) in the US (EPA 2009) and in part of the Canadian national inventory system, Roth-C (Coleman and Jenkinson 1996) in the Australian NGAS system and DNDC (Li et al. 2000) as part of the German national inventory. These types of process models are generally used with detailed activity data sets and supporting ground-based observations for the most advanced Tier 3 inventory approaches.

A major advantage of dynamic process-models for estimation is that they build on a large body of scientific knowledge about the factors controlling SOC changes and that they can integrate climate, soil, management and time as continuous variables – as opposed to using discrete classes as in the case of empirical models. Thus they are, in principle, better able to account for spatial and temporal variability. Disadvantages include that they require more information to run and generally require considerable training to use effectively. However, improvements in software design that include integrated user interfaces, databases and dynamic models are being developed to overcome these limitations. For example, the COMET-VR (Carbon Management and Evaluation Tool for Voluntary Reporting) was developed to support farmer self-reporting of soil C stock changes in the US (Paustian et al. 2009). The system includes an on-line user interface, a large database server, a set of programs for managing data queries and model execution, a simulation model and an empirical uncertainty estimator. The system was designed to allow agricultural producers to self-report and thus it uses a simple web-based interface. User inputs are structured as a series of pull-down menus, which compile the appropriate data (e.g. climate, crop sequences and management practices) from a database server in order to run the Century model simulation to estimate soil C stock changes. Input data are also used to estimate fossil fuel-derived C emissions associated with field operations. A similar farm-scale soil C and GHG tool, using IPCC-type emission factor equations, has been developed for use in Canada (Janzen et al. 2006).

#### 7.2.4.3 Land use and management activity data

Model-based approaches to estimate soil C stock change require information on biophysical attributes that influence soil organic matter dynamics, such as climate variables (e.g. temperature, moisture) and soil physical attributes (e.g. texture, rooting depth), and land use and management ‘activity’ data that record the types of management practices in a particular area or location and how they have changed over time. This information is used as inputs to models such as those described above to estimate SOC changes over time for the area of interest (i.e. local to national scales). Two broad types of information sources are available, ground-based observations and remote sensing.

Ground-based methods generally include traditional agricultural statistics that are collected through farm surveys. The sampling intensity, frequency and data collected vary for different countries although the fairly standard statistics on major crops grown, yield and area are compiled by most countries and global statistics are compiled by FAO. While these data are useful as a first-order estimate of major land use activities, more detailed data and management practices (e.g. fertilization practices, tillage, crop rotations) that are needed for high quality GHG inventories are rarely collected.

#### Remote sensing

Remote sensing (RS) has numerous advantages for the assessment and monitoring of ecosystem properties relevant to soil C dynamics and GHG emissions, but RS also has limitations. Direct measurement of soil C stocks and stock changes in the field is, in general, not feasible with remote

---

12 <http://www.nrel.colostate.edu/projects/ghgtool>

sensing, first and foremost because the soil immediately below the surface is opaque to the portions of the electromagnetic spectrum of interest for detecting organic matter properties. Further, variations in soil moisture, soil mineralogy, residue and vegetation cover make even soil surface C estimates problematic, except for broad differentiation of low vs high organic matter soils (Sullivan et al. 2005, Yadav and Malanson 2007).

However, remote sensing can provide information on many characteristics of the vegetation and residue cover that, in conjunction with model-based systems, can be useful in quantifying soil C stock changes and GHG emissions. Since plant productivity and residue management determine the amount of C that enters the soil, remote sensing of the above-ground plant and residue attributes can provide very useful constraints on models of the soil C balance. Satellite imagery and aerial photography are widely used for determining land cover (e.g., forest, cropland, grass) and thus can provide accurate and low cost quantification of land cover and land use change (Jung et al. 2006), which can be major drivers of soil C stock changes. Identification and mapping of individual crop species is more difficult. However, quite accurate mapping results (>90% fidelity) have been demonstrated for major field crop types (e.g. corn, soybean, wheat) using Landsat TM (Daughtry et al. 2006). Other variables that can be remotely sensed and that can help inform model-based estimates include plant phenology, NDVI, leaf area and photosynthetically active radiation (PAR). Recently, considerable progress has been made in assessing crop residue coverage, which is closely correlated with tillage management, using space-borne hyperspectral instruments. For example, Daughtry et al. (2006) were able to accurately differentiate minimum (conservation) tillage fields from more intensive (reduced + intensive) tillage practices 80% of the time, based on comparisons with ground surveys, in corn and soybean fields in central Iowa. They used a cellulose absorption index (CAI) based on reflectance in the upper shortwave infrared wavelength region, from the EOS-1 Hyperion sensor. Classification into three tillage classes (conservation, reduced, intensive) was less accurate (60%). Further development to correct for interference from certain types of soil minerals and to screen out pixels with more green vegetation could further improve accuracy (Serbin et al. 2009).

#### **Integrated model-based assessment, remote sensing and ground-based monitoring**

The most cost-effective and flexible measurement and monitoring systems of agricultural soil C stock changes will integrate all of the elements described above. Models provide the means of integrating the effects of soil, climate and management influences on emissions and direct measurements provide the 'ground-truth' so that uncertainties to be determined in a robust way. Remote sensing can complement ground-based survey data on land use and management practices and can provide information on crop productivity and other vegetation characteristics that determine the amount of organic matter added to soil through plant residues, which is a major determinant of soil C dynamics. A combined model and measurement system also enables practice-based approaches for monitoring, whereby the performance of a specified set of management activities would be the primary focus of a monitoring program rather than simply direct measurements independent of the practices employed. Low cost and reliable monitoring of agricultural GHG mitigation efforts will require linking remote sensing, soil monitoring networks and well-tested process-based models, into systems that provide consistent estimates with quantified uncertainties, for field scale to national scale application. A pilot project in Saskatchewan provides a useful case study for a broad-scale integrated measurement and modeling approach, where they found that by combining statistical sampling with modeling on 150 farms, they were able to determine significant changes in soil C stocks after three years for costs as low as 10 to 15 cents per hectare (McConkey and Lindwall 1999).

#### 7.2.4.4 Efficiency accounting (emissions per product unit)

Land-use accounting approaches presented above may not adequately represent options which yield significant production efficiency gains, i.e. increasing production without increasing emissions associated with emissions related to expanding agricultural land (e.g. yield gains in crop sector and improved feed conversion efficiency in the livestock sector). Therefore, efficiency accounting approaches measuring the emissions per product unit also referred to the product C footprint, expressed in tCO<sub>2</sub>e/per kg of product are currently developed. Efficiency accounting is based on a product value chain or Life Cycle Analysis (LCA) approach. However, this approach is difficult to apply when a single process generates a range of products, e.g. soy production for oil and feed cakes. FAO is currently in the process of developing standards for the livestock sector, but the work is still in the research stage and not available for use in the framework of national GHG inventories. The main advantage of efficiency accounting is that it provides incentives to increase production efficiency (expressed in unit of CO<sub>2</sub>e emissions per unit of product) and to provide consumers with the opportunity to make an informed decision on their consumption related C impact. In addition, there are a range of livestock mitigation activities that are either captured in the energy sector such as improved manure management or that can only be quantified when efficiency accounting approaches are used, e.g. improving feed conversion efficiency and feed digestibility or increasing yields. Finally, behavioral changes like switching from beef consumption to poultry or reducing the overall protein intake can have great mitigation impacts.

Land-use accounting and efficiency accounting are complementary approaches (Riedacker 2007). The former is widely applied but it is not useful to integrate all agricultural mitigation options along the food chain. It also does not directly address the dual challenge of producing more food while reducing the sector's emissions.

Efficiency accounting is facing the challenge that LCA approaches are relatively complex, data demanding and not yet fully standardized. Depending on the defined value chain, the emissions per product unit will be different. Efficiency accounting can be already adopted for mitigation actions where the inputs and outputs can be quantified. For sectoral accounting, existing statistics for inputs and outputs in developing countries are mostly not sufficient and production and processing chains have to be standardized for accounting purposes before sectoral mitigation approaches can use efficiency accounting, which may also be considered in a pure land-use accounting when defining the BAU and projected mitigation scenario.

### 7.3 Ex-Ante Tool to assess mitigation benefits of investment projects

EX-ACT (EX-ante Appraisal Carbon-balance Tool) is a tool developed by FAO aimed at providing ex-ante measurements of the impact of agriculture and forestry development projects on GHG emissions and C sequestration, indicating its effects on the Carbon-balance<sup>13</sup> (figure 7.3.1).

This ex-ante C-balance appraisal is a land-based accounting system, measuring C stocks and stock changes per unit of land, expressed in tCO<sub>2</sub>e/ha and year. EX-ACT will help project designers selecting the project activities that have higher benefits both in economic and CC mitigation terms (added value of the project) and its output could be used to guide the project design process and decision making on funding aspects, complementing the usual ex-ante economic analysis of investment projects.

EX-ACT has been developed using mostly the Guidelines for National Greenhouse Gas Inventories (IPCC 2006) complemented with other methodologies and review of default coefficients for mitigation

option as a base, so as to be acceptable to the scientific community. Default values for mitigation options in the agriculture sector are mostly from IPCC (2007). Other coefficients such as embodied GHG emissions for farm operations, inputs, transportation, irrigation systems implementation are from Lal (2004). EX-ACT is an easy tool to be used in the context of ex-ante project/programme formulation: it is cost-effective and includes resources (tables, maps) which can help in finding the information required to run the model. It therefore requires a minimum amount of data that project developers can easily provide and that are usually collected in the phase of project appraisal. It works at project level but it can easily be up-scaled to programme/sector level as well as at watershed/district/national/regional level.

EX-ACT consists of a set of linked Microsoft Excel sheets into which the project designer inserts basic data on land use and management practices foreseen under project activities. EX-ACT adopts a modular approach – each module describing a specific land use – and follows a three-step logical framework (figure 7.3.2):

- a. general description of the project (geographic area, climate and soil characteristics, duration of the project);
- b. identification of changes in land use and technologies foreseen by project components using specific modules (deforestation, afforestation/reforestation, annual/perennial crops, rice cultivation, grasslands, livestock, inputs, energy); and
- c. computation of C-balance with and without the project using IPCC default values and – when available – ad-hoc coefficients.

The main output of the tool consists of the C-balance resulting from project activities. As an example, figure 7.3.3 shows the results for a case study in Tanzania: the Accelerated Food Security Project aimed at increasing maize and rice production and productivity in targeted areas through the improved access of farmers to fertilizers and improved seeds. Results show that although expanded fertilizer use will increase GHG emissions, the adoption of improved land and integrated nutrient management practices will contribute to soil C sequestration so that the net project effect will be the creation of a C sink, with positive effects in terms of mitigation.

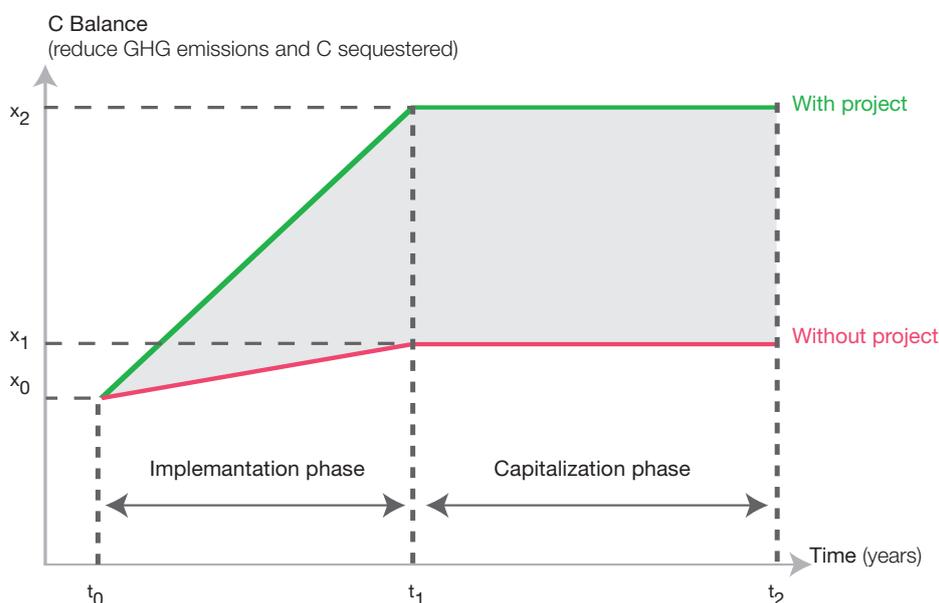
The environmental services (Carbon) supplied by the project, estimated through the C-balance, could then be priced, valued and incorporated in the economic analysis of projects, examining how the discounted measures of project worth (e.g. Net Present Value or Internal Rate of Return) will change when taking into account C sequestration benefits. Also, a set of indicators can complement the economic analysis providing useful information about the efficiency of the project in providing environmental services or the potential contribution of such services to farm incomes.

Initiated for use at project and programme level, the tool can also be used in national sector strategies and policies (e.g. to compute the C balance of aggregated agriculture sector strategies and policy options) or for regional initiatives.

---

13 C balance = reduced GHG emissions + C sequestered above and below ground.

Figure 7.3.1 – The logic behind the EX-ACT tool



## 7.4 External implications of domestic agricultural mitigation policy

In this annex we will elaborate the impact of the climate and development policy in the US and the EU on agricultural mitigation options in developing countries. An international climate convention hopefully provides a framework in which countries can operate. However, considering that the US and the EU combined a considerable share with regards to emissions and development aid (see table 7.4.1) specific consideration will be given to these two.

### 7.4.1 US position on agricultural mitigation in developing countries

The American Clean Energy Security Act (ACESA) introduced successfully in June 2009 to the House of Representatives, and therefore is referred to the Waxman-Markey bill, is set to be presented in the US Senate before December 2009. Therefore, the analyses of the provisions in this bill and its implications for developing countries are the entry point for outlining options for agricultural mitigation in developing countries.

The bill contains provisions for 1 billion tons of international offsets annually and regulated large scale emitters in the US must make use of this provision.

However, only land-based offsets from forestry are specifically mentioned in the bill. International offsets from agricultural activities can be proposed by the Environmental Protection Agency (EPA), but it remains unclear if the EPA has any intention to do this. Including the agricultural sector would not require a new vote on the bill and specific procedures are mentioned in the bill.

The bill stipulates that EPA will prepare a list with developing countries that have relatively high GHG emissions and levels of income that would be capped if they were in the U.S, i.e. large transforming countries like China. Sectors in these developing countries can only import credits into the US if they adopt legally binding sectoral baselines below business as usual and consistent with a maximum global

Figure 7.3.2 – The EX-ACT Structure

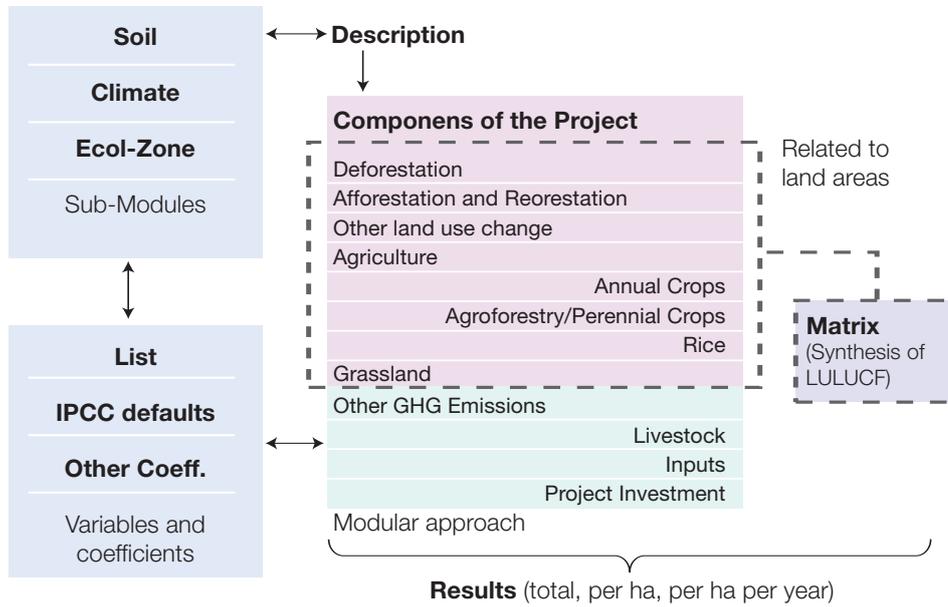


Figure 7.3.3 – An example of EX-ACT output: the Accelerated Food Security Project in Tanzania

Components of the project	Balance with project (tCO <sub>2</sub> for 20 years)
Deforestation	0
Afforestation and Reforestation	0
Other land use change	0
Agriculture	
Annual Crops	-11,252,609
Agroforestry/Perennial Crops	0
Rice	1,736,501
Grassland	0
Other GHG Emissions	
Livestock	0
Inputs	2,418,239
Investments	0
<b>Final Balance</b>	<b>-7,097,869</b>
<b>Total Area (ha)</b>	<b>1,058,385</b>
<b>Mean per ha</b>	<b>-6.7</b>
<b>Mean per ha and year</b>	<b>-0.3</b>

Positive value = Source of GHG  
Negative value = Sink of GHG

carbon budget that will not increase global warming beyond 2°C. Nations and sectors on the list that adopt voluntary no-lose or sectoral intensity targets will not be able to sell offsets to the U.S.

Furthermore, the bill will only issue offsets for projects and programmes of activities until 2017. After that only least developed countries might be able to continue until 2025 with respective mitigation activities. All other mitigation activities have to be implemented as sectoral approaches at country or provincial level. EPA and USAID are in charge to develop MRV standards for international offsets including provisions to account for leakage and permanence.

The US climate bill offers significant options for land-based forestry offsets in the framework of sectoral approaches. The U.S. Secretary of Agriculture recently highlighted during a Africa-US trade meeting that adopting proper agricultural techniques and management can help the world better balance its greenhouse gas emissions.

This highlights different potential scenarios. Assuming that domestic agriculture in the US is not capped, but eligible to sell term offsets with a permanence liability of only 5 years, the same eligibility criteria could be adopted for agriculture in countries that are on the EPA "list" and for other developing countries, as a preferential treatment of agriculture-based countries. Considering the recent statement of the U.S. Secretary of Agriculture, in particular Africa stands a good chance to sell agricultural offsets to the US as an option to recognize that these countries have very low emission levels and therefore have been bypassed at large by the C market.

#### **7.4.2 EU position on agricultural mitigation in developing countries**

Agricultural mitigation activities in developing countries used to sail in the backwash of the REDD plus discussion in the EU, but is now increasingly recognized independently as an important instrument to achieve the ultimate objective of the climate convention, contained in Article 2. This is underlined that just at the beginning of 2009 the European Commission decided that this topic is important and requires a focused negotiator. Unfortunately, in most EU member states combined agriculture and climate change expertise is limited.

The EU according to an unpublished position paper is interested that the agreed outcome in Copenhagen enables the development of sustainable agricultural practices worldwide, contribute to both climate change mitigation and global food security, while facilitating adaptation to climate change. Therefore, they support agriculture in the framework of the AWG-LCA negotiations in the section on NAMAs, cooperative sectoral approaches and sector-specific actions, financing, technology and capacity building.

The EU has not explicitly mentioned what agricultural mitigation mechanism they will support and what funding sources will be provided for agricultural mitigation.

In the framework of the G8 summit in L'Aquila in July 2009 the European Commission promised to contribute about 3 billion for investments in smallholder agriculture in developing countries in the upcoming three years on top of the block's 1 billion food facility announced last year. Considering of the synergies and the overlap between agricultural productivity and food security enhancement activities one option would be to utilize these additional financial resources for supporting combined soil carbon sequestration and food production enhancement actions.

**Table 7.4.1 GHG emissions and development aid in selected countries.**

Country	% of global population	Emission in Mrd tCO <sub>2</sub> e in 2008	Emission per person in 2008	Development aid invested in Mrd \$ in 2007
US	4.6	6.1	19	21.7
EU	7.2	4.5	9	
Australia				2.7
China	20	6.2	4.6	

Source: WBGU 2009, OECD 2009

In general emission trading in land-based sectors is more favorably considered in the US. In the European Trading System (ETS) currently land-based forestry credits are not traded but key members of the European parliament voted to allow forestry credits in the third phase of the EU ETS from 2013 to 2020. This would also be the first option to open the ETS for land based agricultural carbon credits.

Within the EU member states there is an increasing recognition for the demand to reduce agricultural emissions domestically (mainly by conserving organic soils) and sequestering additional soil carbon, as recently presented in the CLIMSOIL Report<sup>14</sup>.

<sup>14</sup> [http://ec.europa.eu/environment/soil/review\\_en.htm](http://ec.europa.eu/environment/soil/review_en.htm)

## 7.5 FAO sources of data relevant for measuring, reporting and verification (MRV) of agricultural mitigation

Source	Type of data	Example of data	link
Aquastat	Global information system on water and agriculture	Statistics on: renewable water resources by country, investment costs in irrigation, irrigation and drainage development, state of water resources and water use, by country and region, by sector and source. Climate Information Tool. Global map of irrigated areas (spatial dataset on areas equipped for irrigation)	<a href="http://www.fao.org/nr/water/aquastat/main/index.stm">http://www.fao.org/nr/water/aquastat/main/index.stm</a>
Climwat and Cropwat	Climatic database	Calculation of crop water requirements, irrigation supply and irrigation scheduling for various crops for a range of climatological stations worldwide. Development of irrigation schedules for different management conditions and calculation of scheme water supply for varying crop patterns	<a href="http://www.fao.org/nr/water/infores_databases_climwat.html">http://www.fao.org/nr/water/infores_databases_climwat.html</a> ; <a href="http://www.fao.org/nr/water/infores_databases_cropwat.html">http://www.fao.org/nr/water/infores_databases_cropwat.html</a>
Countrystat	National statistical information system for food and agriculture	CountrySTAT harmonizes and integrates data on food and agriculture coming from different sources. Through a core database, policy makers and researchers can group data across thematic areas, such as production, trade and consumption, in order to study relationships and processes	<a href="http://www.fao.org/economic/ess/countrystat/en/">http://www.fao.org/economic/ess/countrystat/en/</a>
Faostat	Time-series and cross sectional data relating to food and agriculture	Crops and livestock (primary and processed) and forestry data: production, trade, consumption, prices, food security, land and water, machinery, inputs	<a href="http://faostat.local.fao.org/site/291/default.aspx">http://faostat.local.fao.org/site/291/default.aspx</a>
Fertistat	Fertilizer use statistics	Statistics on fertilizer use by crop for selected key years	<a href="http://www.fao.org/ag/agl/fertistat/">http://www.fao.org/ag/agl/fertistat/</a>
Forestry Country Profiles	Forest facts and information on forests and forestry, by country, for some 200 countries and areas in the world	Statistics on forest and forestry issues on a country by country basis including forest cover, plantations, volume and biomass and fires	<a href="http://www.fao.org/forestry/country/en/">http://www.fao.org/forestry/country/en/</a>
Geonetwork	Geo spatial data, interactive maps, GIS datasets, satellite imagery and related applications	Global data and maps on: soils and soil resources, length of growing periods, thermal climates, hydrology and water resources, land cover and use, population and socio-economic indicators, forest cover and farming systems	<a href="http://www.fao.org/geonetwork/srv/en/main.home">http://www.fao.org/geonetwork/srv/en/main.home</a>
Glipha	Global Livestock Production and Health Atlas	Maps and data on human demographics, land and livestock (production, population, health) by country	<a href="http://kids.fao.org/glipha/">http://kids.fao.org/glipha/</a>
Gtos	Global Terrestrial Observing System	Data on terrestrial ecosystems to support sustainable development: land dynamics, climate observation, terrestrial Carbon	<a href="http://www.fao.org/gtos/index.html">http://www.fao.org/gtos/index.html</a>
Ipnis	Integrated Plant Nutrition Information System	Database providing information for a number of countries on crop-wise plant nutrients management at administrative (district) level, supported by relevant data on soil and soil management, agro-ecological zones, and crop production constraints	<a href="http://www.fao.org/landandwater/agll/ipnis/about.asp">http://www.fao.org/landandwater/agll/ipnis/about.asp</a>

Source	Type of data	Example of data	link
Lada	Land degradation assessment in drylands	Baseline assessment of global trends in land degradation based on: land cover and use, productivity, rainfall, erosion and aridity index data; and global land use systems maps	<a href="http://www.fao.org/nr/lada/">http://www.fao.org/nr/lada/</a>
Terrafrica	Regional sustainable land management	Data on sustainable land management (SLM) approaches in Sub-Saharan Africa	<a href="http://www.terrafrica.org/">http://www.terrafrica.org/</a>
Terrastat	Land resource potential and constraints statistics at country and regional level	Statistics on: major soil constraints, human-induced land degradation due to agricultural activities, land degradation severity and population distribution, deserts and dryland areas	<a href="http://www.fao.org/ag/agl/agll/terrastat/#terrastatdb">http://www.fao.org/ag/agl/agll/terrastat/#terrastatdb</a>
Wocat	World Overview of Conservation Approaches and Technologies	Data on soil and water conservation technologies and approaches	<a href="http://www.fao.org/ag/AGL/agll/wocat/wocatqt.asp">http://www.fao.org/ag/AGL/agll/wocat/wocatqt.asp</a>

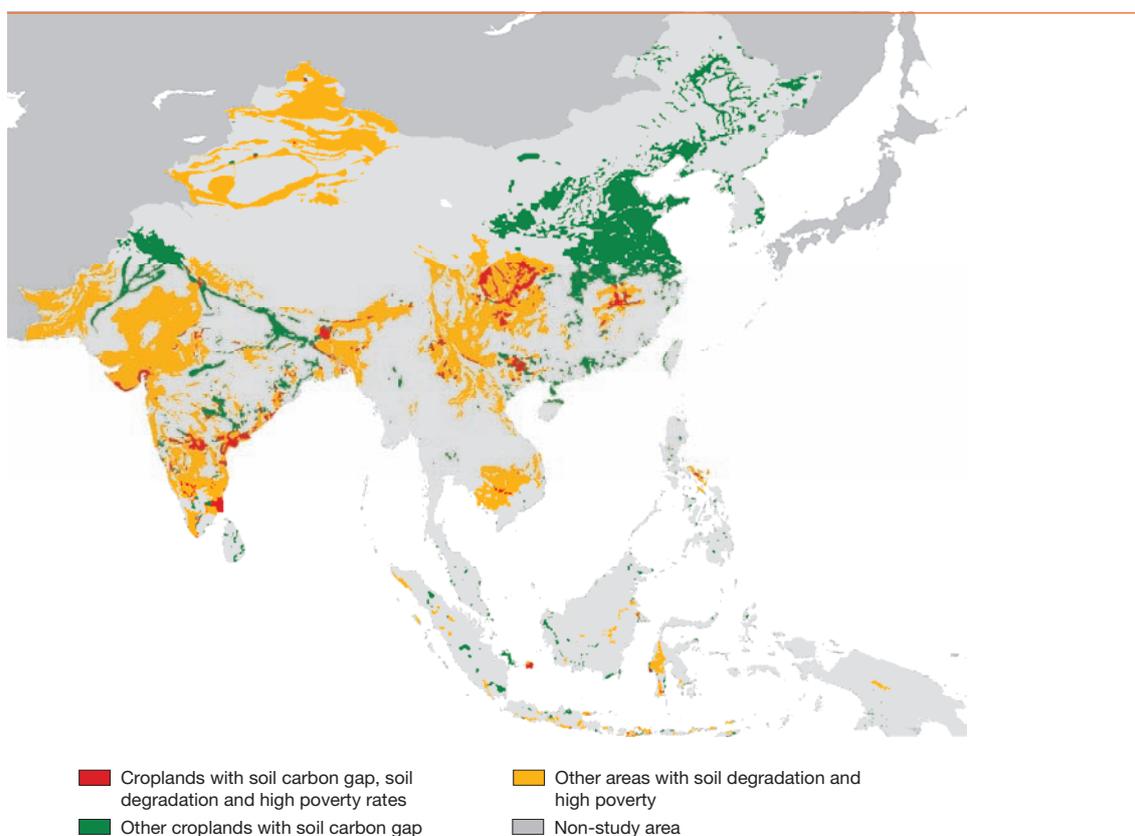
## 7.6 Use of spatially referenced tools to map the opportunities for mitigation: a FAO example from The State of Food and Agriculture (SOFA).

All soils can sequester additional C depending both on local geographical conditions and cropping systems. It is possible to report on a geographical map the areas with significant potential to sequester additional C in soils. This potential (soil Carbon gap) indicates locations where current soil C levels are low, although high sequestration potential exist depending on soil type, climate soil moisture and land cover conditions. Overlaying this map with indicators of poverty it is possible to investigate the potential synergies between soil C sequestration, improvements in soil fertility and poverty reduction.

This type of exercise has been conducted by FAO (2007) and an example of the resulting maps is reported in figure 7.6.1.

The map identifies degraded cropland areas with high soil carbon sequestration potential, overlaid with areas that have a high percentage of stunted children under the age of five. The red areas indicate where supplying soil carbon sequestration might generate a further benefit in the form of poverty reduction. The map suggests that areas in central and western China and central and eastern India are potentially good sites for programmes that combine environmental service and poverty reduction objectives. However, this type of maps is based on global databases at a coarse scale of resolution and with variable accuracy. Therefore, analysis with data at a higher degree of resolution and more detailed information about farming systems and access of the poor to the land will be needed to verify this potential. (FAO 2007).

Figure 7.6.1. Croplands in south and south-east Asia with high human-induced soil degradation, soil carbon sequestration potential and high poverty rates



Source: FAO 2007

## 7.7 Technical background paper on Nationally Appropriate Mitigation Actions (NAMAs) for developing countries in the context of agricultural land management.

### 7.7.1 Background

This annex looks at how to accommodate agricultural characteristics related to different nationally appropriate land-based agricultural mitigation actions (NAMAs) by developing countries. Existing modalities and options to reform them are reviewed as well as options for and experiences from pilot mitigation actions in developing countries. This annex does not make any attempt to provide a comprehensive overview. It mainly serves to illustrate the arguments presented in the main report.

### 7.7.2 How to accommodate agricultural characteristics?

Sectoral approaches for developing countries have been introduced in the framework of the Bali Action Plan (BAP) in order to enhance mitigation efforts. Proposals cover a wide spectrum ranging from public funded policies to crediting mechanisms, which mirror some of the proposals made under CDM reform.

The main options for crediting agriculture mitigation under sectoral mechanisms are related to:

- programme of activities (PoA) using regional baselines, and
- sector or sub-sector approaches based on crediting or trading approaches, e.g. lose or no-lose targets.

### Programmatic approaches

Programmatic approaches also referred to as programme of activities are the most flexible sectoral crediting approach, because they do not require a sectoral crediting baseline or cap on emissions levels. Activities based on a single approved methodology can be adopted independently from the sector as a whole and activities can be implemented by different operators, e.g. from the private sector or non-governmental organizations (NGOs), in a specific geographical region. Compared to stand alone projects, individual activities do not have to demonstrate additionality or be individually validated, and a regional baseline could be used for land-based activities. This would dramatically reduce C related transaction costs. The approach provides the flexibility to up-scale promising agricultural mitigation activities, e.g. sustainable rangeland management over millions of hectares, while benefiting from the reduced transaction costs of the programme framework. Furthermore, these approaches are already eligible under CDM crediting mechanisms and thus can be linked to existing trading systems.

### Sectoral mechanisms

Sectoral crediting mechanisms are based on a reduction of GHG emissions below a defined level, which is credited for an entire sector. Credits are issued for the difference between actual emissions in the sector and a defined crediting baseline (reference level). The latter can be set at the business as usual (BAU) emission level. Some submissions are proposing sector no-lose targets (SNLTs) to set the crediting baseline below the BAU level. Sectoral crediting mechanisms are voluntary and reducing emissions is not legally binding in the existing proposals. It is expected that predominantly sectoral policy measures including research and development (R&D) would be used to foster investment in combined agricultural production enhancement and mitigation actions. Coupled with a national C cap, agricultural producers can generate C credits for a domestic cap and trade system if they emit less than the agreed cap.

Sectors are commonly defined as an aggregated reporting category for the national GHG inventory. In addition sub-sectors may be defined, i.e. cropland management including rice paddies and grazing land management for agriculture. Peatlands and organic soil are other potential sub-sectors that could be considered.

Sectoral mitigation approaches are developed, implemented and monitored at a national level. In the current NAMA framework, unilateral, supported actions and creditable activities are differentiated for sectoral approaches and entail varying types of MRV and crediting schemes. Sectoral approaches fully rely on the capacity of the national regulator for proposing and implementing the mechanism.

One of the disadvantages of sectoral schemes is that C stocks are large compared to potential annual emission reductions or removals and emissions are often non-point emissions. Therefore, high accuracy and costly monitoring systems must be developed and implemented to quantify mitigation performance (see also the section on economics of MRV in the main report and the Annex on MEV). One option could be that the international regulator allows an initial system to operate with a moderate level of uncertainty depending on country capacity and the support provided, and provides incentives to reduce uncertainty over time as capacity and technology advances.

Sectoral approaches require significant capacity to develop baselines and monitoring systems, to define most suitable mitigation actions and to support the implementation of such actions. This capacity is often not present in developing countries. In addition, the considerable variation in production systems

## BOX

### **Sectoral agricultural mitigation, a potential option for increasing fertilizer use efficiency in China**

Sectoral agricultural mitigation approaches are flexible in terms of the measures that can be adopted to reduce emissions and are expected to have low contractual transaction costs, but require substantial investments to establish baselines and sectoral monitoring systems. Therefore, they are most likely initially developed in more economically advanced developing countries like China. In China increasing the fertilizer efficiency is expected to have a significant emission reduction and groundwater pollution reduction due to reduced nitrate leaching. Recent research estimates that up to 95 Wh of energy are used to clean 1 m<sup>3</sup> of nitrogen contaminated drinking water. Thus more efficient nitrogen use will reduce GHG emissions, pollution and save energy. A sectoral approach could be developed with international support related to research and technology transfer.

According to FAO data, China uses on average 250 kgN/ha, which is nearly three times the average fertilizer rate currently used in the U.S.. However, crop production per area is still lower in China and nitrate water pollution is evolving as a major threat in northern China, the main agricultural production area. Improving fertilizer efficiency and reducing current application rates by 50 percent – assuming that this is sufficient to maintaining crop yields – is estimated to reduce embodied emissions by 0.8 tCO<sub>2</sub>/ha. Considering that China is cultivating 130 Mha, the emission reduction potential is great. In addition, this would reduce farmers input costs by about ten percent, hence increasing rural income and helping eradicate extreme poverty in China. Sectoral mitigation approaches can contribute to needed research and extension as well as incentives for farmers to adopt e.g. precision farming and conservation agriculture.

Source: Kahrl and Roland-Holst 2008, Ju et al. 2009

within agricultural sub-sectors, such as extensive pastoralist production together with intensive commercial beef operations, can generate problems in implementing a sector approach. Therefore, sectoral mechanisms are not likely to be very suitable for agricultural mitigation activities in many countries, particularly in the initial phases of implementation.

Non-crediting mechanisms may include Policies and Measures (PAMs) outside the C market or Sustainable Development Policies and Measures (SDPAMs), which are complementary early action approaches. Based on a fund financed by developed countries, capacity and initial incentives can be provided to reduce emissions. Measures also require monitoring, reporting and verification procedures to be effective. Potential drawbacks are the unreliability and unsustainability of financing through public loans and grant finance as well as the governance and sovereignty issues attached to these instruments.

In summary, sectoral approaches are superior in terms of providing flexibility and enabling mitigation action innovation, but the establishment of baselines and the monitoring are extremely demanding. Therefore, to utilize the significant early mitigation action potential of agriculture, a transitioning from project-based baselines to programmatic and sectoral baselines might be appropriate. The length of the transitioning process should be linked to national capacity.

#### **7.7.2.1 Reforming and expanding the CDM**

There is a wide consensus that the existing Clean Development Mechanism (CDM) needs to be further developed. The design of the CDM and lessons learned from the implementation in other sectors provides useful insights for the prospects of agricultural mitigation activities within a CDM-like framework. However, expanding the scope of the CDM in a way that all land-based activities are eligible is not expected to attract substantial investment unless major emission trading systems, such as the

European Emission Trading System (EU-ETS), is also be open for land-based carbon credits.

Options for CDM reform should consider:

- The potential of using project approaches to pilot new methods for agricultural mitigation offsets: project based approaches are useful in piloting new methodologies, in particular for LDCs that have been widely by-passed by the carbon market. Initially project approaches might be a useful learning-by-doing bottom-up approach until the capacity to establish the infrastructure for designing and implementing programmatic and sectoral approaches is available.
- The potential of establishing programmatic or sectoral CDM approaches for agricultural mitigation: consideration of the potential for implementing programmatic and sectoral approaches as either a phased or stand alone option for financing agricultural mitigation is needed. There are considerable benefits that could be obtained from the implementation of such approaches: more flexibility in terms of creating options across a range of different instruments and more efficiency by reducing the demanding and expensive project accounting, reporting and verification procedures. Fixed transaction costs are also a key entry barrier for small-scale agriculture-based C projects. Ongoing experiences with programmatic CDM in the energy sector or microfinance are demonstrating transaction cost efficient aggregation and transaction mechanisms that can reduce transaction costs and potentially enable the 1.4 billion small-scale farmers in developing countries to access the C market. This option is likely to be most applicable to countries where experience with the CDM has already been gained, and with institutional capacity to plan and implement large-scale mitigation activities in the agricultural sector.

There are a number of options for developing cost effective programmatic CDM mechanisms for the agricultural sector that need to be considered:

- the potential of establishing regional baselines covering delineated landscapes, watersheds or production systems;
- the potential of linking C value chains to existing crop value chains (e.g. linking MRV systems that are already in place for quality, organic or fair trade certification of agricultural products); and
- means of establishing ex-ante safeguards to ensure social and environmental integrity to enforce a fair partnership between project developers aggregating carbon and individual participants.







Food and Agriculture Organization of  
the United Nations  
Viale delle Terme di Caracalla  
00153 Rome, Italy  
Tel.: +39 06 57051  
Fax: +39 06 57053152  
E-mail: [FAO-HQ@fao.org](mailto:FAO-HQ@fao.org)  
[www.fao.org](http://www.fao.org)