

The potential of carbon markets for small farmers: A literature review

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Introduction

Since markets for GHG emission reductions have been established, their combined value has increased to more than US\$100 billion in just a few years (Capoor and Ambrosi 2009). However, agriculture has been largely excluded from both formal and informal carbon markets, chiefly because of the high level of uncertainty surrounding agricultural mitigation and the transaction costs associated with smallholder agriculture, which manages most of the agricultural carbon. Key uncertainties include the amount of carbon that can be sequestered by agricultural soils, the reduction in emissions obtainable from the agricultural sector, and the length of time that carbon can be stored in the soil. Transaction costs depend on the costs of monitoring, reporting and verification of changes in soil carbon and emission and on the cost of aggregating and organizing farmers. This paper reviews these challenges and also reviews some the proposed methods to ensure that smallholder farmers have access to the markets that reward climate change mitigation activities. The paper first provides an overview on GHG emissions and the associated mitigation potential of the agricultural sector. This is followed by an overview of the regulatory and voluntary carbon markets that are currently available for emission abatement. After a brief review of the economic literature that analyzes the potential contribution of agriculture to climate change mitigation, the paper describes the opportunities and challenges for smallholders to access payments for environmental services such as carbon markets and ends with a series of final considerations and conclusions.

Agricultural emissions and agricultural mitigation potential

Agricultural emissions account for about 14 percent of total greenhouse gas (GHG) emissions. Furthermore, agriculture is the largest source of non-CO₂ GHG emissions, generating 52% and 84% of total methane and nitrous oxide emissions, respectively. Methane (CH₄) emissions come from organic materials decomposing in oxygen-deprived conditions such as irrigated rice fields, while nitrous oxide emissions are a result of excessive nitrogen which exceeds plant requirements (Smith et al. 2008). Carbon dioxide – CO₂ comes from microbial decay, burning of plant litter and burning of organic matter. However, the net flux of this gas in agriculture is thought to be small (Figure 1).

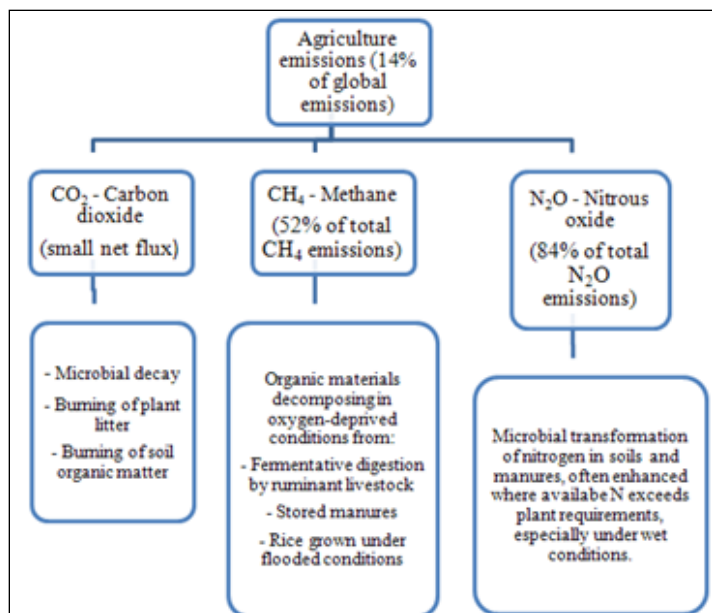


Figure 1. Agricultural GHG emissions

Source: Smith et al. 2008, USEPA (2006b)

Emissions from agriculture are increasing rapidly and are expected to continue to increase over the next decades. According to USEPA (2006b), agricultural emissions are expected to increase from less than 6,000 MtCO₂eq in 2005 to over 7,000 MtCO₂eq by 2020. The largest sources of GHG emissions in agriculture are agricultural soils and enteric fermentation (Figure 2).

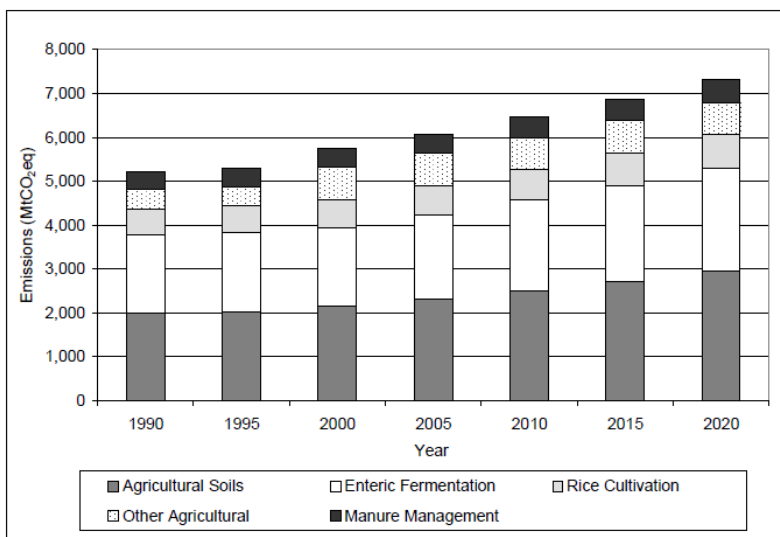


Figure 2. Total emissions from the agricultural sector by source (MtCO₂eq)

Source: USEPA (2006a)/

Compared to 2000 levels, N₂O emissions from agricultural soils are projected to increase by 37 percent by 2020; enteric livestock CH₄ emissions by 30 percent; manure CH₄ and N₂O by 24 percent; and CH₄ from rice cultivation by 22 percent (USEPA 2006b). According to these estimates, emissions will continue to be mainly from agricultural soils and enteric fermentation.

Considering the geographical distribution of emissions, China, India, Brazil and the United States are at the top of the list of the largest emitters of non-CO₂ GHGs from agriculture (Verchot 2007). By 2020, those countries are still projected to be the main emitters of non-CO₂ GHGs from agriculture. Moreover, the cumulative growth rate in business-as-usual emissions of non-CO₂ GHGs is expected to be largest in the Middle East—increasing by 197 percent, followed by Africa, Latin America, South & Southeast Asia, and China & Other Asia with growth of 104 percent, 86 percent, 64 percent, and 58 percent, respectively, compared to 1990 levels. Non-CO₂ GHG emissions from China and India, the top two emitters in the world, are projected to increase about 62% and 72% from 1990 to 2030 (Verchot 2007). In developed countries, emissions will increase at much slower rates with OECD emissions expected to grow at 10 percent over the same timeframe (USEPA 2006a). This is mostly due to population and income growth, rising per capital caloric intake and changing diet preferences in developing countries (i.e. choice of meat and dairy products over grains and vegetables) (USEPA 2006b).

According to Rosegrant et al. (2009), global cereal production is projected to increase 0.9 percent per year during 2000-2050 with growth fastest through 2025 followed by a slowdown afterwards. Demand for meat products (beef, sheep and goat, pork, and poultry) grows more rapidly, but also slows somewhat after 2025, from 1.8 percent per year to 1.0 percent annually. Total cereal demand is projected to grow by 1,048 million metric tons, or by 56 percent; 45 percent of the increase is expected for maize; 26 percent for wheat; 8 percent for rice; and the remainder, for millet, sorghum and other coarse grains. Rapid growth in meat and milk demand in most of the developing world will put strong demand pressure on maize and other coarse grains as feed. Globally, cereal demand as feed increases by 430 million metric tons during 2000-2050, a staggering 41 percent of total cereal demand increase. Slightly more than 60 percent of total demand for maize will be used as animal feed; and a further 16 percent for biofuels. China and India alone will account for 12 percent and 10 percent of the increase in cereal demand.

Although agriculture is an emitter of GHGs, it can also play an important role in mitigating the progression of global warming. Smith et al. (2008) assess the economic potential of agricultural mitigation of GHG emissions including cropland and livestock-based options. The global technical GHG mitigation potential for agriculture by 2030 was estimated to be about 5500-6600 Mt CO₂-eq.year⁻¹. The global economic mitigation potential is presented in Table 1 for various levels of carbon prices.

Table 1. Economic mitigation potential of agriculture by 2030

Quantity – Mt CO ₂ -eq.year ⁻¹	Carbon Prices – US\$ t CO ₂ -eq. ⁻¹	% of total mitigation potential
1500-1600	0-20	35

2500-2700	0-50	43
4000-4300	0-100	56

Source: Smith et al. 2007, 2008.

Despite the fact that the net flux of CO₂ from agriculture is small, much of the GHG mitigation potential in agriculture comes from soil carbon sequestration, particularly through cropland management, grazing land management, restoration of cultivated organic soils and degraded lands (Smith et al. 2008). Table 4 summarizes some of possible mitigation opportunities related to soil management. Rice management and livestock practices have the highest potential for the reduction of methane emissions. (Figure 3).

Soil carbon sequestration is generally considered more viable than N₂O reductions (USEPA 2006b). The mitigation potential presented in Table 1 is 89 percent from reduced soil emissions of CO₂, about 9 percent from mitigation of CH₄, and about 2 percent from mitigation of soil N₂O emissions (Smith et al. 2007). It is important to note that the estimates for the reduction of non-CO₂ gases emissions are highly uncertain: the 95% confidence interval around the mean of 5800 Mt CO₂e obtained by Smith (2007) is 300-11,400 Mt CO₂e (Verchot 2007). Moreover, according to Kim and McCarl (2009), the effect of stochastic factors on soil carbon also makes the quantity of carbon generated under a sequestration project uncertain, which requires that projects have a discount rate for uncertainty.

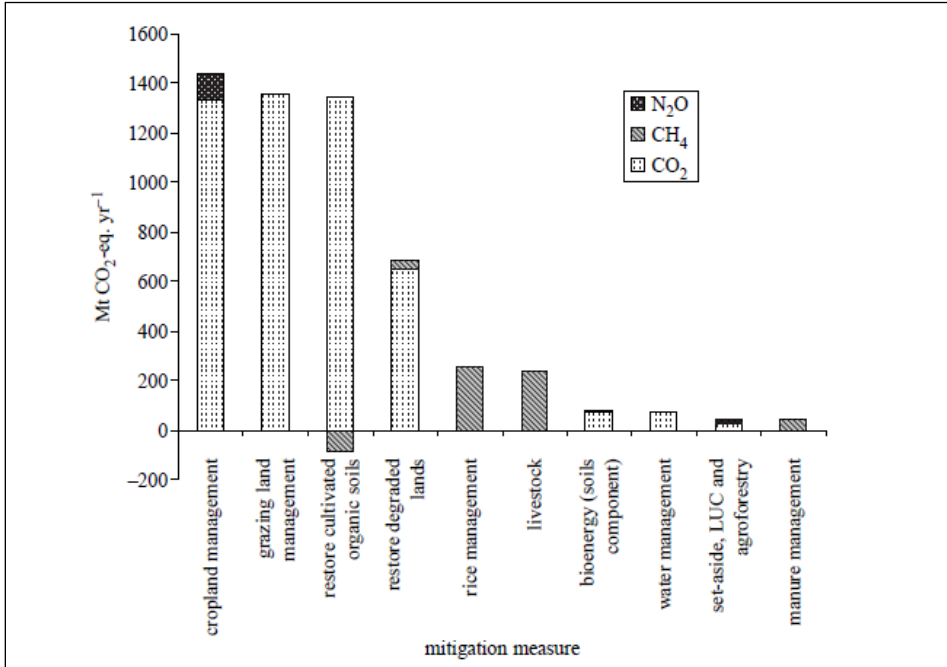


Figure 3. Global biophysical mitigation potential (Mt CO₂-eq. yrK1) by 2030 of each agric. management practice

Source: Smith et al. (2008).

Note: The figure shows the impacts of each practice on each GHG stacked to give the total for all GHGs combined (B1 scenario shown though the pattern is similar for all SRES scenarios).

Figure 4 reports agricultural mitigation potential by location. Among all regions, Southeast Asia has the largest mitigation potential.

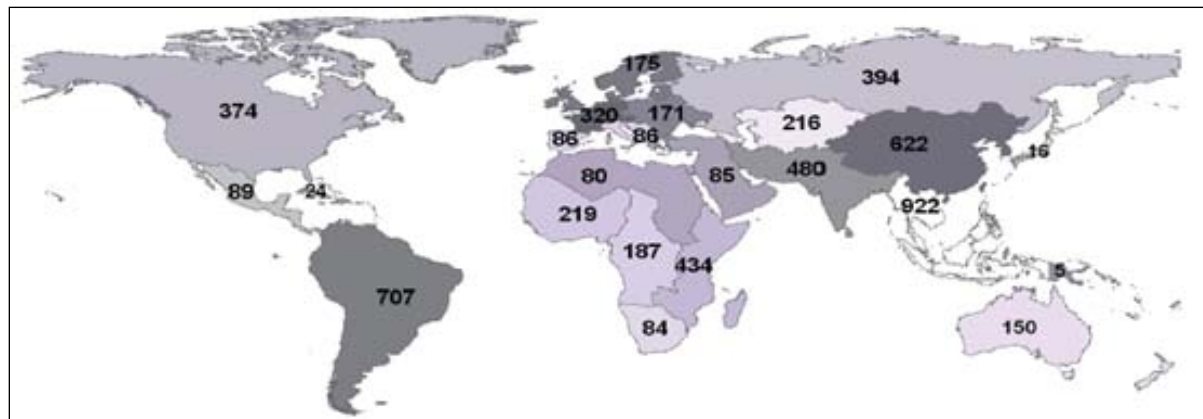


Figure 4. Total technical mitigation potentials (all practices, all GHGs: MtCO₂-eq/yr) for each region by 2030, showing mean estimates.

Note: based on the B2 scenario though the pattern is similar for all SRES scenarios.

Source: Smith et al. (2007a).

Overview of the regulatory and voluntary carbon market

Carbon markets can be divided into two categories: regulatory (compliance) markets and voluntary markets. The recent 2009 United Nations Climate Change Conference in Copenhagen left the regulatory market, created under the auspices of the Kyoto Protocol, unaltered. Important promises of new funding, US\$30 billion a year for three years to help poorer countries mitigate climate change and adapt to it and US\$100 billion a year by 2020 for adaptation-and-mitigation projects in developing countries, were made in the Copenhagen Accord¹. It is unclear, at this stage, how these changes will affect the market mechanisms for helping poor countries, and if the new monitoring, reporting and verification actions agreed upon will actually help to build trust in the carbon markets.

Currently, the only land use, land use change and forestry (LULUCF) practices accepted by the regulatory market are afforestation and reforestation. Soil carbon sequestration projects are excluded.

Furthermore, it also excludes projects that achieve emission reduction from agricultural soils. For example, changes in rice management practices to reduce methane emissions are excluded under the Kyoto mechanism. In the voluntary market, where there are no legally binding agreements, agricultural soil projects represent a small share of the total volume of projects. As it will be seen below, in 2008, such projects represented 15% of Chicago Climate Exchange projects and only 0.5% of the over-the-counter voluntary market. This might be due to problems related to permanence, monitoring and other barriers presented in section 3.

¹ UNFCCC. United Nations Framework Convention on Climate Change. 2009. Copenhagen Accord. Draft decision - /CP.15. United Nations Framework Convention on Climate Change. Available: <http://unfccc.int/resource/docs/2009/cop15/eng/107.pdf>.

Regulatory markets

The regulatory market was implemented under the Kyoto Protocol, which was adopted in 1997 and enforced in 2005. A main feature of the Kyoto Protocol is the commitment of industrialized countries (Annex I countries)² to reduce GHG emissions by an average 5.2% below their 1990 baseline over the five-year period 2008-2012 (UNFCCC 2009). Three market-based mechanisms were offered by the Kyoto Protocol to help countries to meet their emission targets:

- Emissions Trading. This is a system that allows countries to buy carbon credits from other countries. The EU Emission Trading Scheme (EU ETS) is the largest market for GHG emission allowances. In 2008, the EU ETS market traded 3,093MtCO₂e, and the market was valued at \$91,910 million (Capoor and Ambrosi 2009).
- Joint Implementation (JI). This mechanism allows Annex B emitters³ to purchase carbon credits from emission reduction or emission removal projects in another Annex B party. In 2008, 20MtCO₂e of ERUs (Emission Reduction Unit) were transacted, valued at US\$294 million, which represent a 50% decrease in volume compared to 2007 (Capoor and Ambrosi 2009).
- Clean Development Mechanism (CDM). The CDM is also a project-based transaction that allows Annex I parties to accumulate carbon credits by financing carbon reduction projects in Non-Annex I parties (Hamilton et al. 2009). Certified emission reduction (CER) credits are issued for CDM projects.

CDM accounts for the vast majority of project-based transactions. In 2007, it accounted for 87 percent of volume of carbon transacted and 91 percent of total value (Capoor and Ambrosi 2008). In 2008, the CDM market was valued at US\$6,519 million corresponding to a volume of 389 MtCO₂e. Furthermore, the secondary market for CER was valued at US\$26,277 million in 2008 (Capoor and Ambrosi 2009). In 2007, 73% of CDM projects (in terms of volume supplied) were located in China, followed by a distant second place for Brazil and India (6% each).

Countries in Africa and other Asian countries have also emerged in the carbon market and increased transaction volumes, such as Kenya, Uganda, Nigeria and Malaysia, Philippines, Thailand and Uzbekistan. In 2007, buyers (in terms of volume supplied) were mainly from the UK (59%), followed by Europe-Baltic Sea (12%) and Japan (11%) (Capoor and Ambrosi 2008).

At this point, the carbon sequestration potential of the agricultural sector cannot be exploited under the CDM, as only afforestation/reforestation projects are accepted. Furthermore, according to Capoor and Ambrosi (2009), the European Community intends to continue to exclude CDM credits from LULUCF from the EU ETS as a result of issues such as non-permanence, monitoring and reporting requirements (for more details on reasons for exclusion, see the next section).

² Annex I countries are industrialized countries (members of the Organization for Economic Co-operation and Development - OECD in 1992) and countries with economies in transition. Non-Annex I countries are developing countries.

³ Annex B countries are those included in Annex B in the Kyoto Protocol that have agreed to a target for their greenhouse gas emissions, including all the Annex I countries (as amended in 1998) with the exception of Turkey and Belarus (See IPCC glossary available in: <http://www.ipcc.ch/ipccreports/tar/wg3/454.htm>).

The CDM has one approved methodology for nitrogen fertilizer offset through inoculation of legumes (in legume-grass rotations), developed by Perspectives for Amson Technologies (US). The methodology only claims CO₂ reduction through avoided production of fertilizer, but expects inoculant as a mean of reducing N fertilizer (Michaelowa 2009, personal communication).

Voluntary markets

The voluntary carbon market encompasses all exchanges of carbon offsets that are not under regulation. A survey conducted by the Ecosystem Marketplace and New Carbon Finance assessed the state of the voluntary carbon markets in 2008 (Hamilton et al. 2009). This study breaks down the carbon market into two categories: the Chicago Climate Exchange (CCX) and the “Over-the-Counter” (OTC) market. The CCX is the world’s only voluntary cap-and trade system, while the OTC is the non-binding offset market.

The unit of trade of the CCX is the Carbon Financial Instrument (CFI) which represents 100 tCO₂e (tonnes of carbon dioxide equivalent). In order to comply with this market, participants can have CFIs either from allowance-based credits or offset credits from emission-reduction projects. However, only 4.5% of member’s total emissions reduction requirement can be offset through offset-based credits from projects. Therefore, most of the credits traded are allowance-based credits (Hamilton et al. 2009).

In the CCX market, registered projects in 2008 came mostly from coal mine, forestry and renewable energy projects. The United States and Canada had most of registered projects; however, their market share decreased from 79% in 2007 to 60% in 2008, while registered projects in Latin American and Asia increased. Within the registered projects in the CCX, there is a much larger share of agricultural soil projects than any other voluntary markets. However, from 2007 to 2008, this share fell from 48 to 15 percent. According to Hamilton et al. (2009) the drop in agricultural soil projects is due to the growth of the program itself and the consequent slowdown of the verification process, but also to the fact that Canada no longer accepts agricultural soil projects.

Typical agriculture registered and verified projects in the CCX include continuous conservation tillage and conversion to grassland soil carbon sequestration offsets and sustainably managed rangeland soil carbon sequestration offsets. The baseline default rates are 0.12 – 1.0 t CO₂ per acre and year depending on location and project type (Michaelowa, personal communication, Dec 2009).

The vast majority of carbon credits in the OTC market come from emission-reduction projects. The unit of trade in this market is called Verified Emission Reductions (VERs) but CDM units can also be used for voluntary offsetting purposes (Hamilton et al. 2009).

According to the survey results, in 2008 the United States was the largest country supplying carbon credits in the OTC, accounting for 28% of the total, while Asia was the region with the highest market share, supplying 45% of the transaction volume. In Africa, which accounts only for 1 percent of the OTC market, countries with the greatest OTC transaction volume were Madagascar, Uganda, Mali, South Africa, Tanzania, and Eritrea. According to Hamilton et al. (2009), lack of capacity is one of the main reasons that make project development more difficult in Africa.

In 2008, most projects in the OTC market were related to renewable energy (hydropower, wind energy and biomass energy) and landfill gas capture with 51% and 16% of the market share, respectively. Just as in the regulatory market, land-based credits transacted in voluntary markets do not constitute a large share of the market. In 2004, its share in the OTC market was 29 percent while in 2008, it fell to 11 percent (Hamilton et al. 2009). Projects with agricultural soils had 1 percent of the voluntary market share in 2007 and 0.5 percent in 2008 (Table 2).

For the voluntary carbon standard, two methodologies have been submitted including the “Adoption of Sustainable Agricultural Land Management (SALM)” methodology submitted by the World Bank based on two carbon sequestration projects in Kenya and a “General Methodology for Quantifying the Greenhouse Gas Emission Reductions from the Production and Incorporation of Soil of Biochar in Agricultural and Forest Management Systems.” None of these has been approved to date (Michaelowa, personal communication, Dec 2009).

Table 2. Land-Based Credits Sold in OTC, 2007 vs. 2008

Project Type	Volumes of land-based credits (ktCO ₂ e)		Market share of land-based credits relative to the total	
	2007	2008	2007	2008
Aff./Reforestation Mix	673	646	2%	1%
Aff./Reforestation Mono	2,157	3,399	8%	7%
Avoided Deforestation (REDD)	1,421	730	5%	1%
Forestry Management	-	431	-	1%
Agricultural Soil	820	267	1%	0.5%
Other Land-based projects	-	130	-	0.3%
Total	5,071	5,603	16%	11%

Source: Hamilton et al. 2009

The potential of Nationally Appropriate Mitigation Actions (NAMAs)

Nationally Appropriate Mitigation Actions (NAMA) were defined in the Bali Action Plan under the United Nations Framework Convention on Climate Change (UNFCCC)⁴ as voluntary mitigation activities formulated and implemented in developing countries but enabled and supported through finance, technology and capacity-building from developed countries (UNFCCC 2009a). In a three-page political agreement (the Copenhagen Accord) initially drafted by Brazil, China, India, South Africa and the United States, and endorsed by several other countries, the importance of financial, technological and capacity-building support to enable the implementation of mitigation and adaptation actions in developing countries was reinforced. The funding for mitigation actions is expected to come from public and private sources, bilateral and multilateral, including alternative sources of finance.

⁴ The Bali Action Plan established the Ad Hoc Working Group on Long-Term Cooperative Action under the Convention (AWG-LCA), which among other things, has presented the definition and scope of NAMAs.

Since NAMAs are voluntary actions, there is no binding obligation for developing countries. However, NAMAs are commonly thought to have the potential to substantially increase carbon mitigation opportunities for developing countries and several of the already submitted NAMAs⁵ include plans to adopt actions in the agricultural sector, which confirms the potential role of agriculture in NAMAs (FAO 2010). It is unclear, at this stage, what institutional mechanisms and government arrangements to implement the NAMAs will be created. It is essential, therefore, that a better defined and structured document about NAMAs and potential funding be elaborated before COP16 takes place in November 2010 in Mexico City.

Given the lack of clarity on NAMAs, a debate is currently taking place in the international arena on the opportunity of broadening their definition and scope. Among the proposals discussed are Unilateral NAMAs, which are autonomous actions taken by developing countries with domestic funds and therefore no outside support (Levina and Helme 2009), and Credit-Generating NAMAs that are actions that build on supported NAMAs and that – by exceeding an agreed-upon crediting baseline – produce offsets for sale in the global carbon market. The Conference of Parties is responsible for developing the modalities and guidelines for participation in international emissions trading (Levina and Helme 2009, UNFCCC 2009).

A Brief Review of the Economic Literature on Agriculture and Climate Change Mitigation Activities

While agriculture has been widely recognized as a fundamental force in the reduction of poverty, the active role of agriculture in slowing down or even reversing ecosystem degradation is a somewhat new idea. For many years, the problem was framed in terms of a tradeoff between development and environmental degradation. More recently, scientists from different disciplines have posited that the two objectives are not mutually exclusive and that agriculture has the potential to generate both poverty reduction and ecosystem services (Lipper et al. 2009). Economists have studied the use of market forces, as opposed to command-and-control policies, to obtain desirable environmental outcomes. While the payment for environmental services literature was initially mostly focused on forest and water resources, more recently the attention turned to agricultural landscapes and the rural poor who live in environmentally degraded areas. Climate change mitigation activities are just one of the many environmental services that farmers can provide to the global community and as such they could be rewarded. In this section we briefly review the economic literature that focuses on climate change mitigation activities. There is a growing literature that analyzes the economics of farmers' participation and their possible involvement in regulatory and voluntary carbon markets. Most of the empirical literature concentrates on cases in the United States and in Europe. However, some of the findings are general and potentially applicable to small farmers in developing countries.

⁵ Submitted NAMAs are available on the UNFCCC website: <http://unfccc.int/home/items/5265.php>

Conditions for adoption of mitigation practices

The literature that looks at the condition for adoption of mitigation practices is relatively simple. Stavins 1999, Antle 2002; Gonzales-Estrada et al. 2008, among many, assume that a risk-neutral farmer will try to maximize the present value of the stream of net benefits that derive from farming land. Therefore, a farmer will adopt mitigation practices when the net present value of farming with these practices is greater than the alternatives. Farmers might incur additional costs or there might be a temporary decrease in productivity. In these cases, some form of payments could be made available to farmers to overcome the reduction in profit. Even though a considerable amount of research has addressed the impact of risk, uncertainty, and risk aversion on farmers' adoption of technology, particularly in developing countries (Sunding and Zilberman 2001), the literature that concentrates on climate change mitigation activities has so far ignored these issues.

Costs of adoption and barriers

Many studies have indicated that there are substantial barriers that hinder the adoption of climate change mitigation practices and sustainable land management practices in general (Otsuka and Place 2001, Barret et al. 2002, Nkonya et al. 2004 to name a few). These barriers may be due to lack of knowledge, imperfectly functioning markets and consequent lack of credit, or even a drop in yields during the first years of adoption. At the project level, there are important costs that need to be considered. Negotiation, organization, management, monitoring, and enforcement act as potential barriers to the implementation of projects. This is an area characterized by a considerable lack of data; the project-level data available show up-front costs that range from US\$12 to 600 per hectare (FAO 2009). In a review of the literature that reports CDM transaction-cost estimates, Cacho (2009) finds that ex-ante costs vary from US\$34,000-280,000 (negotiation and project approval), and that ex-post cost vary from some US\$6,000 to US\$280,000 (project monitoring, verification, and insurance).

From an economic standpoint, we can differentiate between two types of costs associated with the implementation of contracts for the provision of an environmental service: farm opportunity costs and transaction costs. Farm opportunity costs refer to the costs of resources used on the farm to provide the service. These include the foregone returns from possibly more profitable activities. The second is costs associated with negotiating and implementing contracts, which also include brokerage fees and monitoring compliance with the terms of the contract (in terms of changing practices or carbon accumulation). Contracts are likely to involve a high number of farmers and institutional structures that work as intermediaries between sellers and buyers. These intermediaries will need to group contract agreements from large numbers of farmers to construct a commercially viable contract (for example, the unit of trade for the Chicago Climate Exchange is 100 tonnes CO₂ eq.). Since these intermediaries act as a middle-man, the payments that farmers receive per tonne of sequestered carbon are dependent on transaction costs. Cacho (2009) provides a theoretical demonstration of how increasing the total project area could allow higher payments to farmers. However, this result relies on transaction costs to be kept "relatively fixed", while the costs of negotiation could be increasing with the number of farmers participating in the contract. As Antle (2002) points out, negotiation costs - negotiation with buyers and negotiation with farmers - will also be affected by the total amount of carbon sequestered and sold on the market, the type of soil where the sequestration activity is undertaken, and the institutional setting

in which the transactions take place. As of today, not enough pilot projects have been implemented and not enough data are available to assess the optimal number of farmers that should be organized to participate in soil carbon contracts to minimizing transaction costs.

From an economic modeling perspective, while farm opportunity costs enter implicitly in the economic analysis of adoption of mitigation activities (Stavins 1999, Parks and Hardie 1995), transaction costs have been either assumed equal to zero (Gonzales-Estrada et al. 2008), or they have been simulated for a sensitivity analysis (Antle and Stoorvogel 2008). When the transaction costs are included in the model, simulations show that they have a considerable effect on the adoption of the most desirable practices such as the incorporation of 50 percent of plant residue in the soil: these costs can drive participation down to zero.

Types of contracts

The recent literature on carbon sequestration, in both agriculture and forestry sectors, supports the view that it would be more efficient to implement contracts that pay farmers per tonne of carbon sequestered rather than through contracts that pay for the adoption of specified prescribed management practices. Parks and Hardie (1995) use the opportunity costs of foregone agricultural output to show that the least-cost policy for sequestering carbon by converting agricultural lands to forest is associated with bids offered on a per-tonne basis rather than on a per-acre basis. Pautsch et al. (2001) analyze the potential for carbon sequestration using different tillage practices and reach a conclusion similar to Parks and Hardie regarding the efficiency of per-tonne versus per-acre payment schemes.

A dissenting voice is Stavins (1999), who in an analysis of carbon sequestration in forests finds that a contract based on tonnes of carbon sequestered would be prohibitively expensive to implement due to the costs associated with quantifying the amount of carbon sequestered. Antle et al. (2003) however estimate that the costs to implement the per-tonne contracts are at least an order of magnitude smaller than the efficiency losses of the per-hectare contract. The increased cost of measuring carbon sequestration is counterbalanced by a higher return per dollar spent.

A direct implication is that, given a certain carbon sequestration goal, contracting parties should bear the higher costs of the per-tonne contracts in order to achieve a lower total cost of abatement. The structure and length of a contract can also play a significant role (Lewandrowsky et al. 2004). Lewanowsky et al. propose to structure farmers' compensations as a rental contract for sequestering an amount of carbon for a commitment period. The payment is based on the annualized value of a permanent reduction of a tonne of carbon. There are two advantages in structuring in this fashion rather than an asset payment structure (Antle et al. 2002; and Pautsch et al. 2001), which implicitly assumes that sequestration is permanent. First, it rewards also storage of carbon and it contractually stops when the carbon is released in the atmosphere. Second, given that the decision of adopting mitigation practices generates an opportunity cost, shorter renewable contracts, linked to the market price of carbon, would reflect the changing opportunity cost and encourage farmers' participation. Nelson et al. 2009 suggest using the type of contracts used in the U.S. Conservation Reserve Program in which farmers submit a bid to adopt a set of conservation practices and the bids with the lowest cost

per unit of environmental service are accepted. Similar to Park and Hardie, this type of contract would ensure cost efficiency.

Role of marginal land

Models of farmers' participation in carbon contracts can provide an important insight in the role that marginal land can play in climate change mitigation. The condition for the adoption of mitigation practices is that the net present value of farming using those practices is greater than the alternative uses, net of possible payments. In other words, a farmer incurs an opportunity cost any time that she decides to practice mitigation activities. Antle and Diagana (2003) show that the opportunity cost of alternative land uses is inversely proportional to the soil potential for carbon sequestration. This means that fertile land may have the highest potential for carbon sequestration. Therefore, marginal lands are not necessarily more economically efficient at sequestering carbon, and indeed the opposite may be true. For example, land that produces the largest quantities of crop residues provide farmers with a large amounts of organic amendments available for incorporation. Graff-Zivin and Lipper (2008) reach a similar conclusion. The authors analyze the impact that changes in land quality have on equilibrium soil carbon levels. The impact depends fundamentally on how the marginal benefit from an additional unit of soil carbon and the marginal benefit from additional sequestration activities change with land quality. Their results indicate that farmers who live on land of intermediate quality will sequester the most carbon. This result has important implications regarding the farmers that should be engaged, and in particular poor farmers who most often work on land with poor quality (Lipper 2001). According to this study they would not be good candidates for a carbon sequestration programs.

Monitoring and compliance

Another issue that has attracted considerable attention is the problem of how governments should design compliance monitoring strategies when environmental compliance requirements are not self-enforcing. Payments for climate change mitigation services generally have two common features. First, they are voluntary and second, participation involves a contract between the buyer, an intermediary agent, and the landowner. The landowner agrees to manage the land according to agreed-upon practices and receives a payment conditional on compliance with the contract.

Arising from the mainstream economics area of principal-agent theory with imperfect information, there are two major issues that need to be dealt with when implementing a payment for environmental services such as climate change mitigation activities: adverse selection and moral hazard. Adverse selection arises when negotiating the contract. Landowners have better information than the buying agent about the opportunity costs of supplying environmental services. Landowners can thus secure higher payments by claiming their costs are higher than they actually are. More precisely, landowners use their private information as a source of market power to extract informational rents from conservation agents. These rents are payments above the "true" minimum payment necessary to engage the landowner in a program. Adverse selection has been the subject of theoretical analyses in the context of agri-environmental payment schemes but has not been directly applied to climate change mitigation (Bourgeon et al. 1995; Fraser 1995; Wu and Babcock 1996; Latacz-Lohmann and Van der Hamsvoort 1997; Moxey et al. 1999; Ozanne et al. 2001; Peterson and Boisvert 2004).

The problem of adverse selection is potentially important because the buying agents might obtain fewer environmental services per dollar spent than they would in a world with perfect information. The moral hazard problem arises instead after a contract has been negotiated and is due to imperfect information about compliance. The certification process may require that farmers are monitored for contract compliance but the intermediary agent may find monitoring costly and thus might be unwilling to verify compliance with certainty. Thus, the landowner has an incentive to avoid fulfilling her contractual responsibilities. Hidden action in agri-environmental payment schemes has also been the subject of theoretical analyses (Choe and Fraser 1998 and 1999; Ozanne et al. 2001; Fraser 2002; Hart and Latacz-Lohmann 2004). Most of the economic literature on the subject concentrates on cases in the US and Europe. In the context of agri-environmental policy, Choe and Fraser (1999) derive optimal monitoring strategies and incentive payments when farmers can exert either low or high compliance effort and monitoring is costly. Kampas and White (2004) examine the impacts of monitoring costs on the relative efficiency of alternative agri-environmental policy mechanisms. Fraser (2002) investigates the effects of penalties for non-compliance but does not consider monitoring costs. More recent studies have applied the results of this type of economic analysis to the problems of payments for environmental services, including carbon sequestration (Grieg-Gran et al. 2005). However, several important empirical issues remain unaddressed and should be tested. For example, theoretical analysis by Ozanne, Hogan and Colman (2001) and Fraser (2002) find that risk aversion among farmers ameliorates the moral hazard problem in relation to agri-environmental policy compliance. The implications of their findings are still untested in developing countries.

Challenges for smallholder farmers in accessing carbon markets

Challenges to Participation in Informal Carbon Markets

Even though the mitigation potential of the agriculture and forestry sector is documented (see Smith et al. 2007a and 2008), some experts remain ambiguous about its benefits. The IPCC fourth assessment report (AR4) remains ambiguous about the benefits of soil carbon sequestration, for example, for no-till and restoration of agricultural lands. Moreover, the range of uncertainty over more proven agricultural mitigation practices remains very large, on the order of +/- 50 percent for nutrient management and rice management, for example.

Several other obstacles prevent developing countries from taking full advantage of growing carbon markets. Among others, barriers are of biophysical, economical, social, institutional and political nature.

Antle (2000) lists several important issues that need to be considered when designing carbon contracts. Among these are property rights, transaction costs, and uncertainty. Lack of property rights, including uncertain tenure and land ownership and weak legal institutions can limit the possibility to implement carbon contracts or hinder farmers' participation. Second, transaction costs can be very high and can considerably limit the money available for farmers. Finally, the quantity of carbon being sequestered is spatially and temporally variable. This generates a relatively high degree of uncertainty at the time the contract is traded.

Peskett et al. (2006) review the potential benefits and challenges that small farmers encounter when they participate in carbon offset forestry projects. Uncertainty in the flow of benefit potential and high transaction costs are cited as the two major constraints. The authors mention that under both the CDM and voluntary mechanisms uncertainty regarding who owns the carbon emission reductions can generate disputes and conflicts. Another problem stems from farmers being tied into land use patterns which diverge from local practices known to be effective, which might increase farmers' vulnerability to shocks and economical fluctuations.

Lack of education and access to information may also challenge the effectiveness of projects, giving rise to obstacles, abuses and conflicts (Roncoli et al. 2007). Other issues relate to infrastructural and institutional weaknesses, poor systems of governance and political representation (Roncoli et al. 2004).

Challenges to Participation in Formal Carbon Markets

According to Bryan et al. (2009) there are other impediments-- besides exclusion from the CDM-- that can prevent developing countries from taking advantage of existing carbon markets. These include the need to establish an accurate baseline and demonstrate that emission reductions would not have occurred in the absence of the project (a concept often referred to as the additionality). Cost effectiveness, irreversibility, transaction costs, property rights, and uncertainty are also often cited as important obstacles (Smith and Scherr 2003).

Baseline scenario

Gaining access to formal carbon markets requires the formulation of an accurate baseline scenario. The baseline scenario describes GHG emissions in the absence of a project. For many developing countries, lack of knowledge and technical training as well as poor data availability are major obstacles that need to be overcome to define an adequate baseline (Kelly 1999).

Additionality

A project is said to meet the additionality criterion if the carbon sequestration or emission reductions achieved by the project would not have been obtained in absence of the project. The carbon credits earned are given by the difference in emissions with and without the project. To demonstrate that the additionality criterion is satisfied, plausible alternative scenarios need to be identified. Also, an investment analysis needs to be performed to demonstrate that the proposed project is not the most financially attractive even without carbon payments. Additionality can be difficult to demonstrate for agriculture projects, since many mitigation possibilities are financially viable and may be concurrently occurring. It is therefore, difficult to determine how much of an activity can be attributed to the CDM (Smith et al 2007b).

In addition to problems related to generating a baseline and satisfying the additionality requirement, developing-country participation in carbon offset markets is constrained by a number of other factors.

Leakage

The adoption of certain agricultural practices may reduce emissions in a given area or region. However, emission savings could be offset if the type of agricultural production a project is trying to prevent shifts to other regions where little effort is expended on mitigation measures in agriculture or forest

conservation efforts (Smith 2007b). Community-based agriculture and forestry projects will result in leakages if the project takes over community land and does not adequately compensate the community. For example, projects that displace significant annual crop production need to simultaneously increase the productivity of agricultural land through labor intensive technologies. Thus, livelihood enhancing projects which are likely to adequately meet the needs of local communities reduce the risk of leakage. In practice, however, considerable difficulties may occur in fulfilling community needs in developing countries.

Cost effectiveness

It is difficult to determine the cost effectiveness of alternative projects. Production cost should include transaction, carbon sequestration, and carbon storage costs. Even though the level of carbon benefits used for calculating production costs should be adjusted for additionality and leakage, very few estimates do so. Therefore, most of the figures reported in the literature should be taken as underestimates of the cost of supplying carbon services.

Irreversibility

Developing countries should be aware that they may be facing their own emission reduction commitments in the future. Since many emission abatement measures are irreversible, ignoring possible future commitments could lead to problems. Notably, the cheapest abatement measures will be implemented first, leaving developing countries with only more expensive measures when they have to meet their own commitments in the future.

High transaction costs

The cost of carbon projects include the cost of providing information about carbon benefits to potential buyers, communicating with project partners and ensuring parties fulfill their contracted obligations. Measurement and monitoring costs are also considerable. These transaction costs per unit of emission reduction seem likely to be much higher for projects involving local communities since costs of negotiating land-use decisions with large number of geographically dispersed local people with different land use objectives in developing countries will tend to be higher for a community-managed project than for most strict forest protection or industrial plantation projects. It has therefore been recommended to pool smaller sized community projects to lower project development, marketing, certification and insurance costs (Noble 2003; Smith and Scherr 2003).

Moreover, livelihood enhancing projects such as agroforestry, and community land uses, often face significant institutional barriers such as difficulties in financing establishment costs, obtaining planting materials, lack of technical assistance or marketing infrastructure.

Uncertainty

Uncertainty about emissions, carbon storage processes, and measurements make investors more wary of these options and more likely to choose clearly defined industrial mitigation activities (Smith 2007b). Thus, a greater effort needs to be made to demonstrate the significant savings through agriculture and forestry projects.

Property rights

Currently, land titling is absent in many developing countries. As a result, in the absence of supportive legislation, revenues may be captured strictly by only those who have formal land titles while communities with customary rights are excluded (White and Martin 2002).

Lack of development

In developing countries, mitigation opportunities through clean development are limited as not much industry has been developed; and for example, less than 10 percent of the population has access to the grid for electricity.

Table 3 presents a summary of barriers to implementing agricultural GHG mitigation options, cited by Smith et al. (2007).

Table 3. Barriers to implementing agricultural GHG mitigation options

Barrier type	Description
Permanence	<p>There is a maximum amount of carbon that ecosystems can hold. Therefore, carbon sequestration only removes carbon until that maximum capacity is reached.</p> <p>Changes in management practices can reverse the gains in carbon sequestration (obs: N₂O and CH₄ emission reductions are non-saturating)</p>
Additionality	<p>Some mitigation options are well know and financially viable. Therefore, the GHG net emission reductions need to be additional to what would have happened in the absence of a market.</p>
Uncertainty	<p>Mechanism uncertainty: uncertainty regarding biological and ecological processes involved in trace gas emissions and carbon storage might make investors opt for more clear-cut industrial mitigation activities (there should be more investment in research). Measurement uncertainty: variability between seasons and locations of agricultural systems can translate to high variability in offset quantities at farm level (increasing the geographical extent and duration of the accounting unit can reduce variability).</p>
Leakage	<p>The adoption of agricultural mitigation practices may shift production to other regions where such practices do not exist, resulting in no net reduction of emissions.</p>
Transaction costs	<p>Brokerage cost (getting the commodity to the market) can be a significantly fraction of carbon market prices, especially for small farmers, which can make transactions not economically viable.</p>

Measurement and monitoring costs	There are disagreements about these costs being small or not. Measurement costs per C-credit sold decrease as quantity of carbon sequestered and area sampled increase in size.
Property rights	Property rights and lack of clear land ownership can be impediments for the implementation of management changes

Source: Smith et al. (2007).

Final Considerations and Conclusions

Emissions from agriculture are important contributors to climate change, accounting for approximately 14% of the global total. The share of these emissions is far larger in developing countries, and largest in the least developed countries. If emissions from land use change (18%) were included, the total source for agricultural mitigation practices would be even larger.

There are two potential ways to enhance the pro-poor impact of climate change policy: first, by transforming climate change policy into a pro-poor development strategy to create value for small farmers and investment flows into rural communities in developing countries; second, by effectively integrating the carbon trading process from global governance of carbon trading through sectoral and micro-level design of markets and contracts, to investment in community adaptation policies. These policies require that producers and investors are provided with the incentives to improve agricultural practices and yields in sustainable ways, conserve watersheds to reduce erosion and enhance water filtration, and reforest denuded areas. It is important to note that the benefits that can derive from the implementation of these new policies are both environmental and economic. While agricultural carbon mitigation for smallholder farmers is challenging to implement—as the various barriers to implementation reviewed in this project have clearly demonstrated—the implementation of smallholder agricultural mitigation has so many additional benefits that it should not be difficult to find investors interested in ‘Charismatic Carbon’, that is, carbon credits that have clear poverty reduction, food security and nutrition, and environmental sustainability benefits.

The key components of a successful climate change mitigation project are the capacity to measure and monitor carbon stocks and or emissions reduction accurately and at a low cost, the capability to aggregate farmers so that pools of carbon in tradable amounts are formed, and the existence of financial mechanisms that efficiently connect the demand and supply for carbon offsets. The long term sustainability of a project, however, might depend not only on farmers receiving payments for the environmental services provided, carbon sequestration or ecosystem conservation they may be, but also on its capability of improving their welfare.

Projects performance has been related to the presence (success) or lack (failure) of: financial assistance, funding, extension services, access to seeds and fertilizers, education and information access, off-farm economic alternatives, participatory planning and implementation, capacity building, good governance, conflict management, political stability, civil society organizations participation and, market access,

among others (Jintal et al. 2006, Zhang et al. 2008, Grieg-Gran et al. 2005, Hall 2008, Roncoli et al. 2007, Perez et al. 2007).

A policy environment that enables the necessary institutional mechanisms for community participation in carbon trading is needed. This could require clarifying resource tenure and removing the incentives that promote land degradation (Roncoli et al. 2007). On the other hand, lack of a suitable institutional arrangement might hamper processes of aggregation of carbon credits to be sold in the carbon market, monitoring, and verification (Perez et al. 2007).

In general, when payment for environmental services schemes involve governmental actors they can fall short of funding, can be politically biased when choosing target areas, can experience poor cross-sector coordination and limited implementation capacity (Hall 2008). Therefore, besides appropriate allocation of financial and human resources, a strong political commitment is also needed (Hall 2008). Donor and research institution commitment to promoting reforms, building capacity and ensuring accountability are all necessary (Roncoli et al. 2007). In projects in Africa, non-profit institutions and local governments have taken additional responsibilities besides looking for funds to finance projects, such as capacity building of community representatives and monitoring and supervision (Jintal et al. 2006).

Insecure access to land is one of the factors that might contribute to failures of payment for environmental services schemes, especially if there are no off-farm economic opportunities (Zhang et al. 2008). Private investors may be reluctant to supply capital when projects are implemented in areas with insecure land rights (Jintal et al. 2006) and secure access to land has been positively associated with adoption of improved management practices (Perez et al. 2007). However, based on case studies, Jintal et al. (2006) find that even in areas under customary tenure and land held as common property by entire communities, carbon projects could work.

Lack of coordination and cooperation among different institutions and actors can cause conflicts and duplication of actions (Zhang et al. 2008). Areas that have ongoing tensions over land access and natural resources can lead to further degradation and require dispute resolution mechanisms. Institutional mechanisms are needed for improved conflict management and negotiations among decision-making agents at multiple levels as well as protection of marginalized group interests (Roncoli et al. 2007).

Carbon sequestration projects benefit from context-specific analysis that takes into account the local realities and could benefit from knowledge about past and current land management practices, local ecology and social dynamics and the interactions of social, political, and economic forces (Roncoli et al. 2007).

Project feasibility studies should take into account the disparities in resource endowments, size of the farm, educational level, access to information and financial resources, among others. For instance, Tschakert (2004) shows that the cost of adapting management practices to sequester soil carbon can be higher for poor farmers than for middle- and higher-income farmers. For poor farmers, many management practices can be unaffordable as a result of high initial investment required.

Transaction costs can work as a barrier for the implementation of climate change mitigation projects. Simplified guidelines for the design and formulation of carbon sequestration projects could reduce transaction costs. Transaction costs can also be reduced if projects are located in communities with active local organizations and where participatory development processes exist (Jintal et al. 2006).

In this paper we have reviewed the existing literature on farmers' involvement in the carbon markets. This review indicates that, while the potential for climate change mitigation in agriculture is not as large as the potential for savings from fossil fuels, the contribution is still substantial. The barriers that prevent small farmers from benefitting from the carbon markets are not insurmountable and deserve further study. Finally, we would like note that the potential returns to farmers' involvement is not only their contribution to the problem of climate change. The agricultural practices recommended to sequester atmospheric carbon and reduce emissions also have important environmental co-benefits such as improved quality and flow of ecosystem services. Furthermore, their adoption could contribute to farmers' food security and resilience to climate change.

References

- Antle, J. M. 2000. Economic Feasibility of Using Soil Carbon Sequestration Policies and Markets to Alleviate Poverty and Enhance Sustainability of the World's Poorest Farmers. Paper prepared for presentation at the Expert Workshop on "Carbon Sequestration, Sustainable Agriculture and Poverty Alleviation" held at the World Meteorological Organization (WMO) in Geneva, Switzerland, August 31, 2000.
- Antle, J.M. 2002. Economic Analysis of Carbon Sequestration in Agricultural Soils: An Integrated Assessment Approach. Chapter in *A Soil Carbon Accounting and Management System for Emissions Trading*, Soil Management Collaborative Support Research Program, Special Publication, SM CRSP 2002-4, University of Hawaii, Honolulu, Hawaii, USA, pp. 69-90.
- Antle, J.M., Diagana, B., 2003 Creating Incentives for the Adoption of Sustainable Agricultural Practices in Developing Countries: The Role of Soil Carbon Sequestration. *American Journal of Agricultural Economics* 85(5):1178-1184.
- Antle, J. M., Capalbo, S., Mooney, S., Elliott, E., Paustian, K., 2003 Spatial heterogeneity, contract design, and the efficiency of carbon sequestration policies for agriculture. *Journal of Environmental Economics and Management* 46: 231–250.
- Antle, J. M., Stoorvogel, J.J., 2008 Agricultural Carbon Sequestration, Poverty, and Sustainability. *Environment and Development Economics* 13: 327–352.
- Barrett, J., Vallack, J., Jones A. and Haq, G. 2002 A Material Flow Analysis and Ecofootprint of York: Technical Report, Stockholm, Stockholm Environment Institute.
- Bourgeon, J-P., Jayet, P-A. and Picard, P. 1995. An Incentive Approach to Land Setaside Programmes, *European Economic Review* 39(4):1487-509.
- Cacho, O.J.. Economics of Carbon Sequestration Projects involving Smallholders. *Payment for Environmental Services in Agricultural Landscapes*. Lipper et al. (eds). FAO and Springer Science 2009.
- Cacho, O.J.; Marshall G.R., Milne, M. 2005. Transaction and abatement costs of carbon-sink projects in developing countries *Environment and Development Economics*, 10 (5): 597-614.
- Choe, C. and Fraser, I. 1998. A Note on Imperfect Monitoring of Agri-Environmental Policy, *Journal of Agricultural Economics* 49(2):250-58.
- Choe, C. and Fraser, I. 1999. Compliance Monitoring and Agri-Environmental Policy, *Journal of Agricultural Economics* 50(3):468-87.
- Capoor, K., P. Ambrosi. *State and trends of the carbon market 2008*. Washington, DC: World Bank
- Capoor, K., P. Ambrosi. *State and trends of the carbon market 2009*. Washington, DC: World Bank

- Envirotrade. 2009. *Carbon Livelihoods Projects*. Available in <http://www.envirotrade.co.uk/html/projects.php>. Accessed: August 18, 2009.
- Fraser, I. M. 1995 An analysis of management agreement bargaining under asymmetric information. *Journal of Agricultural Economics* 46(1): 20–32.
- Fraser, R. 2002. Moral Hazard and Risk Management in Agri-environmental Policy. *Journal of Agricultural Economics* 53(3): 475-487.
- Graff-Zivin, J., Lipper, L., 2008 Poverty, risk, and the supply of soil carbon Sequestration. *Environment and Development Economics* 13: 353–373.
- Grieg-Gran, M., I. Porras, and S. Wunder. 2005. How can market mechanisms for forest environmental services help the poor? Preliminary lessons from Latin America. *World Development* 33 (9): 1511-1527
- González-Estrada, E., Rodriguez, L.C., Walen, V.K., Naab, J.B., Koo, J., Jones, J.W., Herrero, M., Thornton, P.K., 2008 Carbon sequestration and farm income in West Africa: Identifying best management practices for smallholder agricultural systems in northern Ghana. *Ecological Economics* 67: 492–502.
- Hall, A. 2008. Better RED than dead: paying the people for environmental services in Amazonia. *Philosophical Transactions of the Royal Society B-Biological Sciences* 363 (1498): 1925-1932
- Hamilton, K., M. Sjardin, A. Shapiro, Marcello, T. 2009. *Fortifying the Foundation: State of the Voluntary Carbon Markets 2009*. A Report by Ecosystem Marketplace & New Carbon Finance. New York: New Carbon Finance, Washington, DC: Ecosystem Marketplace
- Hart, R., Latacz-Lohmann, U., 2004. Combating moral hazard in agrienvironmental schemes: a multiple-agent approach. *European Review of Agricultural Economics* 32 (1): 75–91
- Kampas, A., White, B., 2004. "Administrative Costs and Instrument Choice for Stochastic Non-point Source Pollutants," *Environmental & Resource Economics*, European Association of Environmental and Resource Economists, 27(2): 109-133.
- Kim, M., and B. McCarl. 2009. Uncertainty Discounting for Land-Based Carbon Sequestration. *Journal of Agricultural and Applied Economics* 41 (1): 1-11
- Jindal, R., B. Swallow, and J. Kerr. 2006. Status of carbon sequestration projects in Africa: Potential benefits and challenges to scaling up. WP 26 Nairobi: World Agroforestry Centre
- Latacz-Lohmann, U. and Van der Hamsvoort, C. 1997. Auctioning conservation contracts: a theoretical analysis and an application. *American Journal of Agricultural Economics* 79(2): 407–418.
- Lewandrowski, J., M. Peters, C. Jones, R. House, M. Sperow, M. Eve, and K. Paustian. 2004. Economics of Sequestering Carbon in the U.S. Agricultural Sector. Technical Bulletin No. (TB1909). Washington, DC: U.S. Department of Agriculture, Economic Research Service.

- Lipper, L. 2001 'Dirt poor: poverty, farmers and soil resource investment', in Two Essays on Socio-economic Aspects of Soil Degradation, Economic and Social Development Paper Series no. 149, Rome: FAO.
- Lipper et al. 2009. Payment for Environmental Services in Agricultural Landscapes. FAO and Springer Science.
- Moxey, A., White, B. and Ozanne, A. 1999. Efficient contract design for agri-environmental policy. *Journal of Agricultural Economics* 50(2): 187–202.
- Neff, T. et al. 2009. *The forest carbon offsetting survey 2009*. EcoSecurities, The Climate, Community & Biodiversity Alliance, Conservation International and ClimateBiz. Available in http://www.ecosecurities.com/Standalone/Forest_Carbon_Offsetting_Trends_Survey_2009/default.aspx. Accessed: August 15, 2009.
- Nelson, G.C., Robertson, R., Msangi, S., Zhu, T., 2009. Greenhouse Gas Mitigation: Issues for Indian Agriculture. IFPRI Discussion Paper 177
- Nkonya, E., Pender, J., Jagger, P., Sserunkuuma, D., Kaizzi, C. K., Ssali, H. 2004 Strategies for sustainable land management and poverty reduction in Uganda. International Food Policy Research Institute. Research Report No. 133. Washington, DC.
- Ozanne, A., Hogan, T. and Colman, D. 2001. Moral hazard, risk aversion and compliance monitoring in agri-environmental policy. *European Review of Agricultural Economics* 28: 329–347.
- Otsuka, K. and Place, F., 2001. "Land tenure and natural resource management," Food policy statements 34, International Food Policy Research Institute.
- Parks, P.J., Hardie, I.W., 1995 Least Cost Forest Carbon Reserves: Cost-Effective Subsidies to Convert Marginal Agricultural Land to Forest. *Land Economics* 71 (1): 122-136.
- Pautsch, G.R., L.A. Kurkalova, B.A. Babcock, and C.L. Kling. 2001. The efficiency of sequestering carbon in agricultural soils. *Contemporary Economic Policy* 19(2): 123–134.
- Perez, C., C. Roncoli, C. Neely, and J. L. Steiner. 2007. Can carbon sequestration markets benefit low-income producers in semi-arid Africa? Potentials and challenges. *Agricultural Systems* 94 (1): 2-12
- Peskett, L., C. Luttrell, and D. Brown. 2006. *Making voluntary carbon markets work better for the poor: the case of forestry offsets*. Forestry Briefing 11 London: Overseas Development Institute.
- Roncoli, C., C. Jost, C. Perez, K. Moore, A. Ballo, S. Cisse, and K. Ouattara. 2007. Carbon sequestration from common property resources: Lessons from community-based sustainable pasture management in north-central Mali. *Agricultural Systems* 94 (1): 97-109

Rosegrant, M.W., C. Ringler, A. Shinha, J. Huang, H. Ahammad, T. Zhu, S. Msangi, T. Sulser, and M. Batka. 2009. Exploring alternative futures for agricultural knowledge, science and technology (AKST). FR2009-34. ISBN:978 1 921615 32 0. Australia. ACIAR. <http://www.aciar.gov.au/publication/FR2009-34>

Smith, P., D. Martino, Z. Cai, D. Gwary, H. Janzen, P. Kumar, B. McCarl, S. Ogle, F. O'Mara, C. Rice, B. Scholes, O. Sirotenko, M. Howden, T. McAllister, G. Pan, V. Romanenkov, U. Schneider, S. Towprayoon, M. Wattenbach, and J. Smith. 2008. Greenhouse gas mitigation in agriculture. *Philosophical Transactions of the Royal Society B-Biological Sciences* 363 (1492): 789-813

Smith, P., D. Martino, Z. Cai, D. Gwary, H. Janzen, P. Kumar, B. McCarl, S. Ogle, F. O'Mara, C. Rice, B. Scholes, O. Sirotenko, M. Howden, T. McAllister, G. Pan, V. Romanenkov, U. Schneider, and S. Towprayoon. 2007. Policy and technological constraints to implementation of greenhouse gas mitigation options in agriculture. *Agriculture, Ecosystems & Environment* 118 (1-4): 6-28

Smith, P., D. Martino, Z. Cai, D. Gwary, H. Janzen, P. Kumar, B. McCarl, S. Ogle, F. O'Mara, C. Rice, B. Scholes, O. Sirotenko, 2007a. Agriculture. In *Climate Change 2007: Mitigation*. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Stavins, R. N., 1999 "The Costs of Carbon Sequestration: A Revealed-Preference Approach." *American Economic Review* 89, no. 4: 994-1009

Sunding, D., and Zilberman, D. (2001). The Agricultural Innovation Process: Research and Technology Adoption in a Changing Agricultural Sector. In: Gardner, B.L., and Rauser, G.L. (eds.): *Handbook of Agricultural Economics*. Vol. 1A. Elsevier Science B.V., Amsterdam: North-Holland

Tschakert, P. 2004. The costs of soil carbon sequestration: an economic analysis for small-scale farming systems in Senegal. *Agricultural Systems* 81 (3): 227-253

UNFCCC. 2009. Kyoto Protocol. United Nations Framework Convention on Climate Change. Available in: http://unfccc.int/kyoto_protocol/items/2830.php. Accessed: 11/05/09.

United States Environmental Protection Agency (USEPA). 2006a. *Global Anthropogenic Non-CO2 Greenhouse Gas Emissions: 1990-2020*. Washington, DC: United States Environmental Protection Agency

United States Environmental Protection Agency (USEPA). 2006b. *Global Mitigation of Non-CO2 Greenhouse Gases*. Washington, DC: United States Environmental Protection Agency

Verchot, L.V. 2007. *Opportunities for climate change mitigation in agriculture and investment requirements to take advantage of these opportunities*. A report to the UNFCCC Secretariat Financial and Technical Support Programme. Nairobi: World Agroforestry Centre.

Walker, S., T. Pearson, P. Munish, S. Petrova. 2008. *Carbon market opportunities for the forestry sector of Africa*. Winrock International. FAO African Forestry and Wildlife Commission 16th Session, Khartoum, Sudan 17-24 February 2008.

Wu, J. and Babcock, B. A. 1996. Contract design for the purchase of environmental goods from agriculture. *American Journal of Agricultural Economics* 78(4): 935–945.

Zhang, L., Q. Tu, and A. P. J. Mol. 2008. Payment for environmental services: The sloping land conversion program in Ningxia autonomous region of China. *China & World Economy* 16 (2): 66-8

Table 4. Mitigation opportunities in agriculture

Mitigation opportunity	Category	Examples	Mitigative effects	Problems
Cropland management	Improved agronomic practices	<ul style="list-style-type: none"> - Improved crop varieties - Extending crop rotation - Avoiding or reducing use of bare (unplanted) fallow - Adding more nutrients when deficient - Less intensive cropping systems (reduce reliance on pesticides and other inputs) - Temporary vegetative cover between agricultural crops 	- Increase soil C storage	Benefits from adding N fertilizer can be offset by higher emissions of N ₂ O from soils and CO ₂ from fertilizer manufacture
	Nutrient management (higher N use efficiency)	<ul style="list-style-type: none"> - Precision farming - Using slow-release fertilizer forms or nitrification inhibitors -Using slow-release fertilizer forms or nitrification inhibitors -Avoiding time delays between N application and plant N uptake -Placing the N more precisely into the soil to make it more accessible to crops roots -Avoiding excess N applications, or eliminating N applications where possible 	<ul style="list-style-type: none"> -Reduce emissions of N₂O - Indirectly reduce emissions of CO₂ from N fertilizer manufacture 	
	Tillage/residue management	<ul style="list-style-type: none"> -Reduced tillage -Non-till -Systems that retain crop residues -Avoiding the burning of residues 	-Soil C gain	- Reduced or no till may affect N ₂ O emissions but net effects are inconsistent
	Water management	<ul style="list-style-type: none"> - Expanding irrigation areas -Using more effective irrigation measures -Drainage of agricultural lands in humid regions can promote productivity ?? 	-C storage in soils	<ul style="list-style-type: none"> - CO₂ from energy used to deliver water may offset gains -N₂O emissions might increase as a result of higher moisture and fertilizer N inputs
	Rice management	<ul style="list-style-type: none"> -Draining the wetland rice once or several times during the growing season 	-Reduce emissions of	-Drainage might increase N ₂ O emissions and practice may be constrained by water

		<ul style="list-style-type: none"> - Rice cultivar with low exudation rates - Keeping the soil as dry as possible and avoiding waterlogging during off-rice season. -Adjusting the timing of organic residue additions -Composting the residues before incorporation or producing biogas for use as fuel for energy production 	CH ₄	supply
	Agroforestry	-Production of livestock or food crops on land that also grows trees, either for timber, firewood or other tree products.	<ul style="list-style-type: none"> -Higher stock of carbon above ground -Carbon sequestration 	-Effects on N ₂ O and CH ₄ emissions are not well known.
	Land cover (use) change	<ul style="list-style-type: none"> -Converting arable cropland to grassland -Converting drained croplands back to wetlands 	-Increase storage of C	<ul style="list-style-type: none"> -Converting drained croplands back to wetlands might stimulate CH₄ emissions -Lost of agricultural productivity
Management of organic soils		<ul style="list-style-type: none"> -Avoiding row crops and tubers -Avoiding deep ploughing -Maintaining a more shallow water table -Avoiding the drainage of these soils or re-establishing a high water table were GHG emissions are still high 	-Reduce emissions of CO ₂ and N ₂ O	
Restoration of degraded lands		<ul style="list-style-type: none"> -Revegetation (planting grasses) -Improving fertility by nutrient amendments -Applying organic substrates such as manures, biosolids and composts -Reducing tillage and retaining crop residues -Conserving water 	-Restoring C storage	-Where practices involve higher nitrogen amendments, the benefits of C sequestration may be partly offset by higher N ₂ O emissions.

Source: Smith et al. 2008.