Challenges and opportunities for mitigation in the agricultural sector

Technical paper

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Contents

Key messages

- Agriculture accounts for 10-12% of the total global anthropogenic emissions of GHGs or between 5.1 and 6.1 GtCO_2e per annum. Between 1990 and 2010 emissions increased by around 18%, with a greater increase after 2005.
- The technical mitigation potential of agriculture (considering all gases and sources) by 2030 is estimated to be between 4.5 and 6 Gt CO_2e yr^{-1}. The economic potential of all agricultural management practices by 2030 is considerably lower than the technical potential.
- About 30 percent of this potential can be achieved in developed countries and 70 percent in developing countries.
- Agricultural GHG mitigation options are cost competitive with options in other sectors (e.g., energy, transportation, forestry) in achieving long-term (i.e., 2100) climate objectives.
- Similar to other economic sectors, mitigation efforts in agriculture can be adopted in the context of a multilateral international agreement, as part of a development national strategy, or as a voluntary initiative by the private sector.

Scope and purpose

The Alliance of Small Island States (AOSIS) has requested CIFOR to prepare a technical paper on challenges and opportunities for mitigation in the agricultural sector. In response to the request, this technical paper provides information that aims to contribute to the better understanding of both the challenges and the opportunities associated with the implementation of approaches and strategies relating to the mitigation of emissions from the agricultural sector. The paper provides an overview of possible practices (existing and under development), addresses the relative potential, methodological and technical challenges, and possible barriers for their implementation, with the aim to inform the discussions of AOSIS within the UNFCCC when considering the role of the agricultural sector for mitigating Climate Change.

The paper covers emissions from enteric fermentation, manure management, agricultural soils, rice cultivation, burning of savannahs and agricultural residues. Other activities covered include soil carbon sequestration in agricultural soils and the agro-forestry systems. The report focuses on two non-CO_2 greenhouse gases: nitrous oxide (N_2O) and methane (CH_4). The report does not cover deforestation emissions associated with land use change to agriculture. However, we note that deforestation emissions are comparable with non-CO_2 greenhouse gas (GHG) emissions in terms of impacts on the atmosphere, using a 100 year time horizon for the analysis.

The report comprises two main parts. The first section provides background information on the development of (GHG) emissions from the agricultural sector, trends of emissions and their projected growth. Mitigation potentials and costs for agriculture, including livestock, crops, soils, land-use change, bioenergy, carbon sequestration and energy in agriculture, are addressed in the second part of this paper. Finally, a detailed Annex provides an summary of existing and emerging or future mitigation practices, highlighting opportunities and challenges for each practice, including barriers to implementation, methodological aspects of each practice and identifies win-win options, best practices and, when applicable, co-benefits and synergies. Knowledge gaps and R&D needs on mitigation practices are identified as the basis of recommendations for future work.

Emissions from agriculture

Agriculture provides the primary source of livelihood for around 18% of the world's workforce, and is involved in the production of the food needed to sustain the seven billion people living on our planet. According to ILO data, three billion people live in rural areas and agriculture is a source of livelihoods for 86 percent of these people. In developing countries of Asia and the Pacific, the percentage of the population working in agriculture ranges from 40 to 50 percent, while in developed countries this proportion is 1 to 5 percent (FAOSTAT, 2014; ILO, 2014).

Agricultural lands are lands used for production and consist of cropland, managed grassland and permanent crops including agro-forestry and bio-energy crops. They occupy about 40 percent of the Earth's land surface (FAOSTAT, 2014) and are expanding. Most of the agricultural lands are used for pasture (~68 percent), approximately 28 percent are arable lands, mainly devoted to annual crops, and only a small part (<3 percent) for permanent crops.

Croplands comprise arable and tillable land, rice fields, and some agro-forestry systems (Eggleston et al., 2006). They include all annual and perennial crops as well as temporarily fallow land (i.e., land set at rest for one or several years before being cultivated again). Annual crops include cereals, oil seeds, vegetables, root crops and forages. Perennial crops include trees and shrubs, in combination with herbaceous crops (e.g., agro-forestry) or as orchards, vineyards and plantations such as cocoa, coffee, tea, oil palm, coconut, rubber trees, and bananas.

Since 1961, the global agricultural production has been increasing steadily (at an annual average growth rate of 2.3 percent) driven by an increasing population, technological change, public policies, and economic growth. During the same period, an average of 6 million ha of forestland and grassland have been converted to agricultural land annually. Production of food and fibre has kept pace with the sharp increase in demand in a more populated world (annually growing 1.7 percent for the period 1961–2006). However, this growth has been at the expense of increased pressure on the environment, and depletion of natural resources (Tilman et al., 2011; West et al. 2014), and it has not fully addressed the problems of food security and poverty in poor countries.

Several studies have suggested that food production needs to increase by between 60 and 110 percent by 2050 to feed the planet's growing human population (Ray et al., 2013). According to OECD projections (OECD/FAO 2014), agriculture is expected to grow rapidly in Latin America, Africa Eastern Europe and parts of Asia, moderately in most developed countries, emerging economies and economies in transition, and to decline in Japan. For livestock populations, high growth rates are expected in Africa, India, South and Southeast Asia, and Middle East, moderate growth rates in most developed countries, emerging economies and economies in transition, and livestock numbers are expected to decline in Japan.

Such scenarios are driven by greater food demand for an increasing human population -projected to be about 9 billion people by 2050, an increasing global gross domestic product (from USD 9,253 per capita in 2004 to USD 17,196 per capita in 2030 (Lupien and Menza, 2008; UNFCCC, 2007), and an increasing share of animal products in the human diet. Most of the growth is expected to happen in the developing world as a consequence of rapid economic development and lifestyle changes.

Sources of emissions

Agriculture accounts for about 10-12% of the total global anthropogenic emissions of GHGs or between 5.1 and 6.1 $GtCO_2e$ per annum. Between 1990 and 2010 emissions increased by around 18%, with a greater increase after 2005. Emissions are expected to continue to increase due to increased demand for food as populations grow, and shifts in diets as societies in developing countries become wealthier and meat consumption increases. There are two types of emissions from agriculture:

- Non-CO_2 GHGs from management operations = 6.3 Gt CO_2e
- Energy related CO_2 emissions (including emissions from manufacture of fertilizer) = 0.6 Gt CO_2e

A third type of emission from land-use change often associated with agriculture is also large, at around 3 to 10 Gt CO_2e (IPCC 2014). Deforestation emissions will not be addressed in this paper, as they are generally treated as an issue for the forestry sector. Energy is also typically treated as a sector. The focus of this paper is on non-CO_2 GHG emissions in agriculture. The GHGs of concern in agriculture are methane (CH_4) and nitrous oxide (N_2O). Additionally, the paper will look at the potential for C sequestration in agricultural soils. The following sections provide brief descriptions of the origins and mechanisms for the release of GHGs from key agricultural activities and draws from the UNFCCC Technical Paper: FCCC/TP/2008/8.

Enteric fermentation

Methanogenic bacteria that exist naturally in the ruminal microflora are responsible for the formation of CH_4 inside the digestive system of animals. Enteric emissions depend on the average daily feed intake and the percentage of the food converted to CH_4. Average daily feed intake can vary considerably and is related to the species, weight of the animal, and its rate of weight gain. For dairy cattle, the rate of milk production is also important. Non-dairy cattle produce about half as much methane per head as dairy cattle. Other parameters affecting enteric CH_4 emissions are genetic characteristics of the animal breeds and environmental conditions.

Manure management

The decomposition of manure under anaerobic conditions (i.e., in the absence of oxygen) during storage and treatment produces CH_4 and N_2O. The main factors affecting CH_4 and N_2O emissions are the amount of manure produced and the portion of the manure that decomposes anaerobically. The former depends on the rate of waste production per animal and the number of animals, and the latter on how the manure is managed. When manure is stored or treated as a liquid (e.g., in lagoons, ponds, tanks, or pits), it decomposes anaerobically and can produce a significant quantity of CH_4. The temperature and the retention time of the storage unit greatly affect the amount of methane produced. When manure is handled as a solid (e.g., in stacks or piles) or when it is deposited on pastures and rangelands, it tends to decompose under more aerobic conditions and less CH_4 and N_2O is produced (Eggleston et al., 2006).

Soils

Agricultural soils emit N_2O as a result of management practices. Nitrogen additions are a common practice for increasing crop yields, including application of synthetic N fertilizers and organic amendments (e.g., manure), particularly to cropland and grassland. This increase in soil N availability increases N_2O emissions from soils as a by-product of nitrification and denitrification. Nitrogen additions by grazing animals (in dung and urine) can also stimulate N_2O emissions. Similarly, land-use change enhances N_2O emissions if associated with heightened decomposition of soil organic matter and subsequent N mineralization. Increases of N_2O emissions are usually accompanied by increases in soil emissions of NO_X and volatilization of NH3.[1] Both of these lead to increased indirect emissions of N_2O as they are redeposited on the soil surface. As they re-enter the N cycle, additional N_2O emissions are created.

Rice cultivation

[1] Emissions of NO_x and NH_3 are regulated by the Convention on Long-Range Transboundary Air Pollution.

In flooded conditions, such as wetland environments and rice paddies, a significant fraction of the decomposing dead organic matter and soil organic matter is returned to the atmosphere as CH_4. About 90 percent of the world's harvested area of rice paddies is located in Asia, and about 60 percent of this is located in India and China. With typically flooded soils and relatively high N input, there is a potential for high emissions of CH_4 during flooded periods and high N_2O emissions during non-flooded periods. These emissions are affected by several factors related to both natural conditions and to crop management (Wassmann et al. 2000, Setyanto et al. 1997, Corton et al., 2000, Wang et al., 2000, Adhya et al., 2000, and Chareonsilp et al. 2000).

<u>Soil organic matter</u>

Agricultural management activities (for example residue management, tillage management, fertilizer management) modify soil carbon stocks by influencing the carbon flows into and out of the soil system. Depending on the management practice, agriculture could become a source or a sink of carbon and, consequently, of CO_2 (Ogle et al., 2005; de Moraes Sá et al., 2009; Verchot et al., 2011).

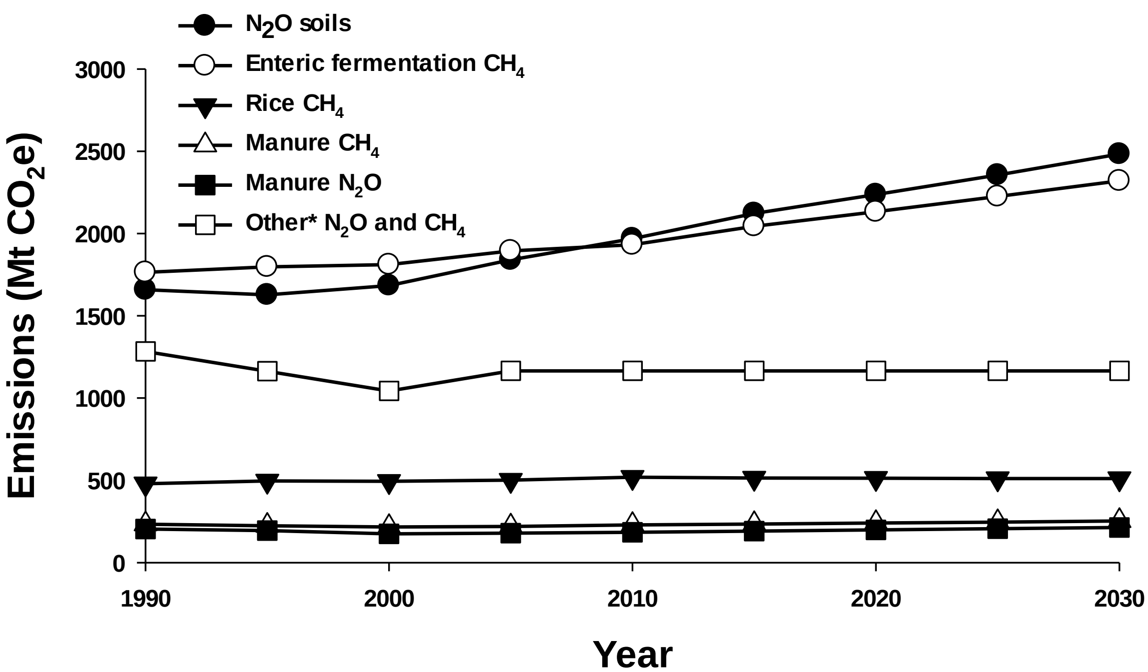
Emissions levels and trends

All data used for this analysis come from the US Environmental Protection Agency report *'Global Anthropogenic Non-CO2 Greenhouse Gas Emissions: 1990 – 2030'* (USEPA 2012a). The text below summarizes the main conclusions of this report.

Agriculture accounts for 5.5 – 6.9 Gt CO_2e per year (or about 13 percent) of the total global anthropogenic emissions of GHGs (Smith et al; 2007; USEPA 2012a). Between 1990 and 2010, global emissions from agriculture increased by 7 percent; the average annual growth being about 19 Mt CO_2e (Figure 1). Emissions area expected to grow by 17% compared to 2010 levels by 2030. In 2010, methane and nitrous oxide accounted for about 3.1 and 2.9 Gt CO_2e per year, respectively, or about 43 percent of total anthropogenic methane and about 82 percent of total anthropogenic nitrous oxide emitted globally.

Soil N_2O and enteric fermentation emissions of CH_4 accounted for 33 percent and 32 percent respectively of agricultural emissions in 2010. Emissions from agricultural soils are projected to increase by 31 percent by 2030, with its share of the sector's total emissions growing to 36 percent. Enteric fermentation emissions are expected to grow by 22 percent from 2010 to 2030, and its relative share of agricultural emissions will increase to 33 percent. Other emission sources will grow at more modest rates (<15%).

Figure 1: Trends for global non-CO_2 GHG emissions (Mt CO_2 eq) by source through 2020

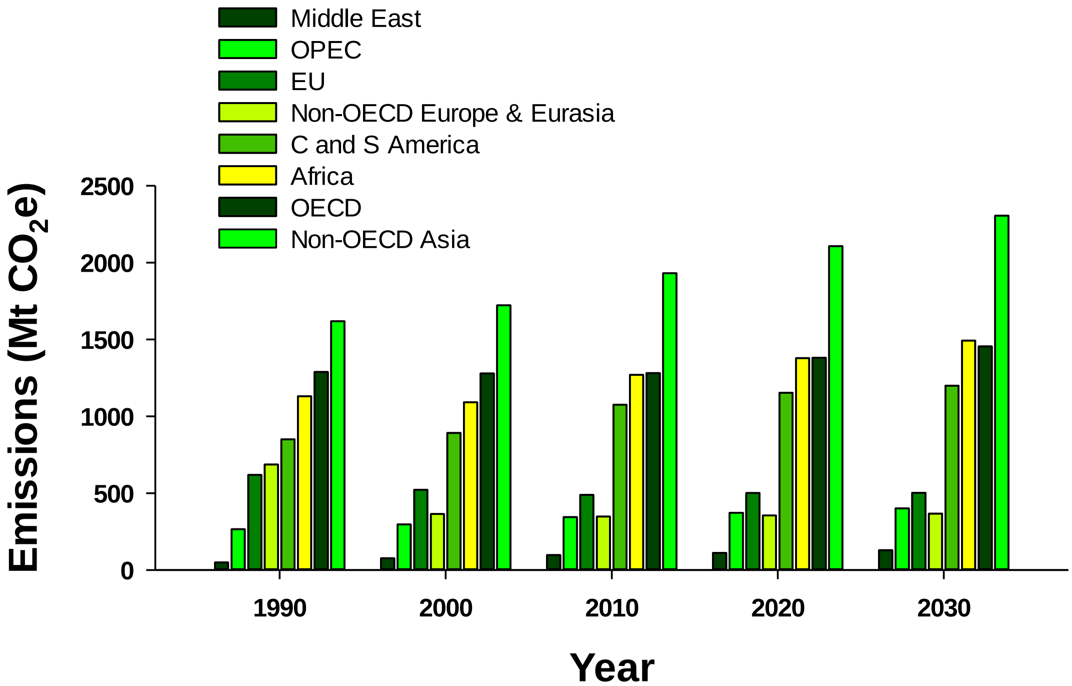


Data source: USEPA, 2012a
* Note: "Other N_2O and CH_4" refers to emissions from biomass burning.

In the absence of mitigation measures, emissions from agriculture are projected to continue to grow over the next two decades (Figure 2). Between 1990 and 2010, agricultural emissions in developing countries increased by 18 percent, resulting in these countries being responsible for about 71 percent of total agricultural emissions in 2010. Emissions in these countries are likely to grow another 16% by 2030 compared to 2010 levels. Between 1990 and 2010, agricultural emissions in OECD countries decreased by about 1 percent; emissions in the EU have decreased by 21% during this period. Emissions of non-CO_2 GHGs were highest non-OECD Asia (Figure 2) and this is likely to continue into the future. Latin America and Africa will also experience increased emissions with 2030 emissions projected to be 41 and 32 percent higher than 1990 emissions, respectively.

Although in all regions, the dominant sources are N_2O emissions from soils and CH_4 emissions from enteric fermentation, each region has additional large sources of emissions. In particular, CH_4 emissions are high from rice cultivation in non-OECD Asia and OPEC; CH_4 and N_2O emissions from biomass burning are high in Sub-Saharan Africa and in South and Central America; CH_4 emissions from manure management are high in the EU (data not shown; cf. USEPA 2012a).

Figure 2: Regional non-CO_2 GHG emissions from agriculture and projections to 2020



Data source: USEPA, 2012a.

Mitigation of Agricultural GHG emissions

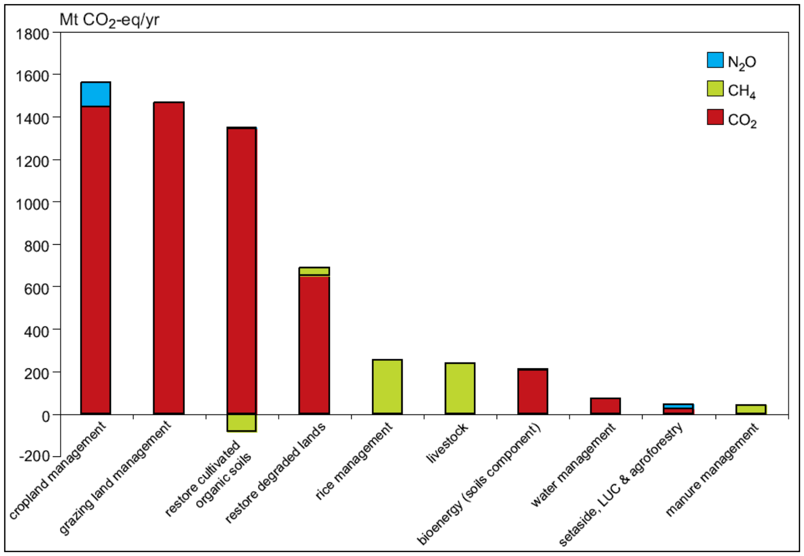
Global mitigation potential and costs

Several mitigation options exist for reducing GHG emissions from agriculture, including: improved livestock and manure management; improved cropland and grassland management (e.g., improved agronomic practices including nutrient use, tillage, and residue management); restoration of drained organic soils for crop production; restoration of degraded lands; reducing fertilizer-related emissions; reducing CH_4 emissions from rice; set-asides, reducing land-use change emissions (e.g., conversion of cropland to grassland or forestland) and agroforestry; sequestration of carbon in agro-ecosystems; producing fossil fuel substitutes. For many of these mitigation opportunities, existing technologies can be implemented immediately, provided economic, financial, social, cultural and educational barriers are overcome. Options are summarized in the annex to this report and a detailed summary can also be found in Chapter 11 of the WGIII report from the IPCC AR5 (pages 23-35).

The technical[2] mitigation potential of agriculture (considering all gases and sources) by 2030 is estimated to be between 4.5 and 6 Gt CO_2e yr^{-1} (Smith et al., 2007). About 89 percent of this potential can be achieved by soil carbon sequestration through cropland management, grazing land management, restoration of organic soils and degraded lands, bioenergy and water management (Figure 3). Mitigation of CH_4 can provide an additional 9 percent through improvements in rice management, and in livestock and manure management. The remaining 2 percent can be achieved from mitigation of N_2O emissions from soils mainly through crop management.

[2] Technical potential is the amount by which it is possible to reduce GHG emissions or improve energy efficiency by implementing a technology or practice that has already been demonstrated. No explicit reference to costs is made but adopting ‘practical constraints’ may take into account implicit economic considerations.

Figure 3: Global technical mitigation potential by 2030 of each agricultural management practice showing the impacts of each practice on each GHG



Source: Smith et al., 2007
Note: The analysis is based on the B2 scenario though the pattern is similar for all SRES scenarios.

The economic potential[3] of all agricultural management practices by 2030 is considerably lower than the technical potential. About 30 percent of this potential can be achieved in developed countries and 70 percent in developing countries. Agricultural GHG mitigation options are cost competitive with options in other sectors (e.g., energy, transportation, forestry) in achieving long-term (i.e., 2100) climate objectives (Smith et al; 2007). The USEPA assessed GHG abatement costs on a number of technical options to illustrate the potential for reducing the different agricultural sources of emissions in its report '*Global Mitigation of Non-CO_2 Greenhouse Gases: 2010-2030'* (USEPA 2012b). The results of that assessment show:

- At a relatively low carbon price of $5 per tCO_2e, net GHG abatement potential for non-rice cropland soils is approximately 65 Mt CO_2e, or about 13% of 2010 baseline emissions. Mitigation potential decreases to 10% of the sector's baseline emissions in 2020 and 6% in 2030. A large part of this abatement potential is through sequestration in agricultural soils and the analysis makes some optimistic assumptions about the ability of reduced tillage to sequester carbon. Nevertheless, the results illustrate that the potential abatement decreases over time because soils reach a new equilibrium carbon content within a few years of changed management.

- For rice production significant reductions are also feasible even at a low values per tCO_2e. Emissions reductions of 13% could be achieved in 2010 at $5 per ton of CO_2e and in 2030, 12 percent reductions are feasible.

- Marginal abatement cost curves were calculated for the livestock sub-sector assuming the production of livestock products remains constant. Maximum abatement potential this case was 268 Mt CO_2e in

[3] Economic potential is in most studies used as the amount of GHG mitigation that is cost-effective for a given carbon price, based on social cost pricing and discount rates, including energy savings, but without most externalities. Theoretically, it is defined as the potential for cost-effective GHG mitigation when non-market social costs and benefits are included with market costs and benefits in assessing the options for particular levels of carbon prices (as affected by mitigation policies) and when using social discount rates instead of private ones. This includes externalities, i.e., non-market costs and benefits such as environmental co-benefits.

2030, or about 10% of annual emissions. With carbon prices below $5 per ton of CO_2e, approximately 86 MtCO_2e of emissions could be avoided. The case where the number of animals was held constant rather than holding production constant gave 15 to 40 percent lower emission reduction potentials.

That analysis was based on a very low carbon value. Table 1 summarizes the results for potential mitigation with a higher carbon price of $30.

Table 1: Estimated emissions reductions from non-CO_2 and soil carbon GHGs (MtCO_2e) and the cost to achieve these reductions ($ billion) between 2010 and 2030 at a carbon price of $30 t$CO_2$e (2010 $)

	Year					
	2010		2020		2030	
Sub-Sector	**Reductions**	**Cost**	**Reductions**	**Cost**	**Reductions**	**Cost**
Cropland	120	3.6	82	2.5	68	2.0
Rice	140	3.9	150	4.5	150	4.5
Livestock	139	4.2	151	4.6	165	4.8
Total	**399**	**11.7**	**384**	**11.6**	**378**	**11.3**

Data source: USEPA abatement curves (USEPA, 2012b).

Mitigation practices

Several publications have summarized the means for achieving mitigation of agricultural GHG emissions. Chapter 11 of the recent IPCC AR5 report has an analysis of the potential for mitigation of these emissions and discusses the concerns of achieving emissions reductions while promoting sustainable development in rural areas. The UNFCCC technical paper on agriculture (FCCC/TP/2008/8) has a very detailed analysis of mitigation options. Annex II of that publication is included in the annex to this document. A summary of these practices is presented in this section, which draws directly from FCCC/TP/2008/8.

Emissions from soils

As mentioned above, soils represent one of the most important sources of non-CO_2 GHG emissions from agriculture. The principal mitigation practice is the reduction of N_2O emissions from excess fertilizer application while maintaining high yield rates for crops. This can be achieved through several approaches, including reductions of fertilizer use, timing fertilizer application to meet crop needs, and the use of nitrification inhibitors, which reduce the conversion of ammonium to nitrite.

Enteric fermentation

Livestock management and the use of dietary additives can reduce enteric CH_4 emissions. Feeding practices with dietary supplements (probiotics, propionate precursors, ionophores, etc.) are more easily applied to confined animals, but higher mitigation potential is related to grazing animals. To improve the animal diet quality, efforts to optimize feeding practices and pasture management are gaining traction. Across developed and emerging economies, animal husbandry is transitioning from predominantly grazing conditions (extensive systems, strongly influenced by environmental conditions) to confined systems (intensive systems, rather independent from environmental conditions), where diet manipulation and administration of additives is more feasible. As a consequence of changes in the diet, manure composition may change in the sense of lower nitrogen content leading to lower N_2O emissions.

Manure management

Several practices can be applied to reduce methane emissions from manure. CH_4 capture (e.g. using bio-digesters, covered piles and lagoons, etc.) allows for either flaring or burning the CH_4 to produce energy and producing CO_2, which has a lower warming potential. Other practices include aerobic treatment of manure (e.g. composting, aerobic animal waste treatment, aerobic soil application of manure) cooling to a temperature below which CH_4 is formed (around 10ºC), and mechanical separation of solids and handling the manure in solid form. For the majority of these practices, additional research is needed to obtain estimates of their mitigation potential (Hao et al, 2008).

N_2O emission from manure management is a function of the amount of manure produced, manure management, and animal diet. To reduce N_2O emissions from manure, the main mitigation practices include: the reduction of nitrogen content (through changes in animal diet); optimizing soil application and avoiding application on wet soils (rainy season); use of nitrification inhibitors in soils or manure piles; increasing the hippuric acid content in the urine through diet changes; use of benzoic acid to affect microbial activity in general and denitrification specifically (Her and Huang 1995; Fenner et al. 2005; Kool et al., 2006; de Klein and Eckard, 2008).

Methane emissions from rice cultivation

Permanent flooding favours the formation of methane in soils, whereas even short periods of soil aeration significantly reduce emission rates. Ample and evenly distributed rainfall can create soil conditions comparable to irrigated rice in some rain-fed systems (Khalil and Shearer, 2006). Persistent flooding throughout the growing season, which is relatively common during the wet season in much of Southeast Asia, also leads to high emissions. Changes in water management, such as mid-season drainage, can significantly reduce emissions (Corton et al, 2000, Wang et al. 2000, and Wassmann et al. 2000).

The quantity and quality of organic inputs are an important factor in determining CH_4 emissions. Traditional agriculture uses relatively large amounts of manure and returns rice straw to the soil, leading to high emissions. Practices that decrease low-quality organic matter inputs to soils can also reduce emissions. However, there are trade-offs, as drainage usually increases N_2O emissions, particularly in fertilized systems. Unfortunately, these trade-offs are poorly quantified (Verchot et al., 2004).

Bioenergy from agriculture

Bioenergy (used to replace fossil fuels) is obtained from agricultural feed-stocks and dedicated energy crops. Its potential, however, depends on the availability of land, which, in some cases, is also needed for edible crops. Estimates of energy production potential from agricultural residues vary between 15 and 70 EJ (exajoules) per year, while energy supply available from agricultural biomass is projected to be in the range of 100 EJ to 400 EJ per year by 2050. Energy cropping on current agricultural land, with projected technological progress in agriculture and livestock production could deliver over 800 EJ per year without jeopardizing the world's food supply (Smeets et al. 2007).

There are many promising technologies for converting biomass into energy. The contribution of biofuels in the reduction of GHG emissions depends on: whether they can be produced on local farms at prices competitive with traditional agricultural products; whether the energy derived from these crops will be cost competitive with fossil-energy sources; whether using land for energy production rather than for producing food is socially acceptable; and whether the ecological and economic benefits of biofuels will be factored into the pricing/evaluation equation (Paustian et al. 2004).

Sequestration strategies

Carbon sequestration in agroecosystems holds great promise as a tool for climate change mitigation (Lal, 2004; Albrecht and Kandji, 2003) especially because they also offer opportunities for synergy with development objectives. For improved grasslands, high rates of sequestration can be achieved by introducing more productive grass species and legumes. Improved nutrient management and irrigation can also increase the productivity of grazing animals and sequester more carbon.

Grazing land management and agro-forestry offer significant potentials for carbon sequestration. Grazing land management, despite the low carbon densities in these lands, has potential because of the large amount of land susceptible for this improvement. Sequestration can be achieved through introduction of more productive grass species and legumes. Improved nutrient management and irrigation can also increase productivity and sequester carbon. It should also be noted that many grassland species have developed adaptation mechanisms resulting to both the vegetation and soil carbon being relatively resistant to moderate destructions from grazing and fire (Milchunas and Lauenroth, 1993).

Agroforestry also offers the potential for synergies between expanding the role of agroforestry in mitigation programs and adaptation to climate change (Verchot et al., 2007). Then introduction of trees into farming systems produces longer term carbon storage in these systems. In humid climates agroforestry systems can store as much as 10 times the carbon of annual cropping fields (Verchot et al., 2004). In many instances, improved agroforestry systems can reduce the vulnerability of small-scale farmers to inter-annual climate variability and help them adapt to changing conditions.

Other land-use options such as restoration of degraded land and wetland have relatively low potentials, globally, to contribute to mitigation, although locally their potential may be significant. These low values are the combined result of low area availability and slow carbon accumulation rates. Reflooding of peatlands is thought to recreate anaerobic conditions and stop peat emissions, which in many climates are very high.

The scientific community has not resolved the issue of the potential for soil sequestration of atmospheric CO_2 in agricultural soils and the conditions necessary for successful long-term carbon storage. Several studies looked at surface soils concluded that reducing tillage increases soil C (Kern and Johnson, 1993; Bayer et al., 2000; Machado and Silva, 2001; Tan and Lal, 2005). More recent studies have shown that reducing tillage in the mid-west of the North American continent and in the Brazilian cerrado simply results in redistribution of the carbon within the soil profile and that there is likely a small net loss over the entire soil profile (Baker et al., 2007; Jantalia et al., 2007; de Moraes Sá et al., 2009). Other work in Brazil (Sisti et al., 2004; Denf et al., 2007) suggests that introducing legumes into the crop rotation alters the dynamics of soil organic matter results in accumulation. This practice would need to be balanced by considerations of the likely increased N_2O emissions from nitrogen fixed by the legume.

The way forward

Agriculture is a significant contributor to increasing atmospheric GHG concentrations and the data presented in this paper suggests that there is significant technical and financial potential for reducing emissions from this sector. Further work is needed to improve assessments of GHG emissions from agriculture, to improve management practices to ensure environmental integrity, to design efficient policies to implement GHG mitigation, and to strengthen the potential of agriculture to contribute to producing renewable energy. Identifying synergies and co-benefits that may exist in relation to climate change policies, sustainable development, food security, energy security, and improvements in environmental quality would make mitigation practices more attractive and acceptable to farmers, land managers and policymakers. Understanding tradeoffs is equally important so that appropriate decisions can be made.

Better country-specific information on the mitigation potential of different practices for agriculture will help countries design the most appropriate portfolios of mitigation practices. The information on mitigation potential contained in the IPCC AR4, AR5 and FCCC/TP/2008/8 provides a good starting point, but does not provide the necessary level of regional/national disaggregation needed for national implementation. In the Annex to this document tables of relevant mitigation practices are provided, but further work in this area, including more country-specific information, is necessary to maximize the effectiveness of the potential portfolios of measures to be implemented.

Policymakers need to consider the full range of policy measures, including the establishment of financial incentive mechanisms to promote wider adoption of best practices in agriculture that reduce GHG emissions. For emissions abatement, incentives could be created through modalities such as JI, CDM and NAMAs. Agricultural mitigation options are gaining importance in the CDM already, and sectoral approaches could also be considered.

The issues described in this paper could inform Parties at the upcoming UNFCCC discussions on the challenges and opportunities for mitigation in the agriculture sector. There are also opportunities through the expert workshops to be held in the coming year to deepen understanding of the mitigation opportunities in agriculture. While the debate is often couched in terms of a tradeoff between climate change mitigation and food security, it is useful to note that food security is rarely an issue of food production and more often a question of availability and access to food. In many parts of the world the causes of inadequate food access are poverty, environmental stressors and conflict, not production (Miselhorn 2005). Given the importance of the sector to agricultural emissions and the vulnerability of agriculture to climate change and climate variations, it will be essential to find ways to produce more food while emitting less GHGs. The science of mitigation in agricultural production systems is maturing and progress can be made if the right incentives are put in place. Those incentives should also include support to national scientific organizations to generate more country and region specific knowledge to support better, less polluting agricultural practices.

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Annex: Summary of Mitigation Options in Agriculture from FCCC/TP/2008/8

Annex: Summary of Mitigation Options in Agriculture from FCCC/TP/2008/8

Annex II

Table 28. Current mitigation practices in livestock-related greenhouse gas emissions

Practices	Sub-group of practices	Gases affected	Relative mitigation potential (per unit of production, others)	Methodologies used to estimate emissions (other relevant elements to measure, report and verify)	Challenges/ barriers and feasibility, including information on cost-opportunity and cost-effectiveness (whenever possible)	Co-benefits and contribution to sustainable development	(Environmental) risks/impacts
Animal population reduction		Methane (CH_4) Nitrous oxide (N_2O)		Tier 1 (2006 IPCC Guidelines for National Greenhouse Gas Inventories (hereinafter referred to as 2006 IPCC Guidelines), Volume 4, Ch10)	- National regulations (standards, compensation and incentives) are needed; - Lack of or poor statistics; - Market influences (more food needed); - Increase in the cost of the product; – Variability in the meat market; - Increasing 'green market'.	Increased sustainability of pastures and carbon sequestration, avoiding degradation of more lands	May affect rural employment and food provision May increase meat and milk costs, thus limiting their consumption in poor communities
High performance animal selection	Animal selection and breeding	CH_4 N_2O (*)	CH_4 *Dairy Cows*: 0.4–5 % *Beef Cattle*: 0.6–7 % *Sheep*: 0.04–0.4 % *Dairy Buffaloes*: 1–0.3 % *Non-Dairy Buffaloes*: 2–7 % N_2O*:* 3%	Emissions Factors by experimental measurements. Tier 1 or Tier 2 (2006 IPCC Guidelines, Volume 4; Ch.10)	- Breeding: barriers are research facilities, financial funds for long-term programmes - Farm selection: barriers are farmers' education and specific technical information. - Increasing 'green market'	Relative CH_4 emission reductions on the basis of kg CH_4 per kg of product, as co-benefit of high performance animals. Reduced pressure on natural resources allow higher levels of sustainability	Not expected

Table 28 (continued)

Practices	Sub-group of practices	Gases affected	Relative mitigation potential (unit of production, others)	Methodologies to estimate emissions (other relevant elements to measure, report and verify)	Challenges/ barriers, feasibility, including information on cost-opportunity and cost-effectiveness (whenever possible)	Co-benefits and contribution to sustainable development	(Environmental) risks/impacts
Feeding practices	Increased livestock nutrient use efficiency. Grain supplementation. Improvement in forage quality, mineral and/or salt supplements.	CH_4 N_2O	CH_4: *Dairy Cows*: 1–18 % *Beef Cattle*: 1–14 % *Sheep*: 1–4 % *Dairy Buffaloes*: 4–10 % *Non-Dairy Buffaloes*: 2–5 % CH_4: 5 % for every 10 % of individual productivity increase.	*Option 1*: Tier 3. *Option 2*: Emission Factors (field/ experimental measurements) and Tier 2 for emissions. *Option 3*: Emission Factors and emissions by Tier 2 (2006 IPCC Guidelines, Vol. 4; Ch. 10)	Main barriers include: Research and laboratory facilities, technical information on the advantages of improving animal performance. Economic incentives can accelerate the adoption of technologies. Need of technology transfer.	CH_4 emission reduction, as co-benefit of improving animal performance. Compatible with sustainable development. Higher profitability in production systems of animal products.	Risk of increasing N_2O emissions from manures and soils where manure is applied. Risk of mineral/salt supplementation having an effect on human health.
	Increase in livestock nutrient use efficiency.	NO_2 CH_4 CO_2	NO_2: 6–45 % CH_4: Not estimated CO_2: Not estimated				Not expected

Table 28 (continued)

Practices	Sub-group of practices	Gases affected	Relative mitigation potential (unit of production, others)	Methodologies to estimate emissions (other relevant elements to measure, report and verify)	Challenges/ barriers, feasibility, including information on cost-opportunity and cost-effectiveness (whenever possible)	Co-benefits and contribution to sustainable development	(Environmental) risks/impacts
Feeding practices (continued)	Grain replacing forage.	CH_4 N_2O	CH_4: 17–40 % N_2O: 25–59 %				Risk of increasing N_2O emissions from manures and manure-applied soils.
	Improvement in forage quality as a result of forage species inclusion. Use of silage and other practices.	CH_4	CH_4: 5–44 %				Risk of increasing N_2O emissions from manures and manure-applied soils.
	Including physical treatment of forage. Plant breeding programmes.	CH_4 N_2O (*)			Research and laboratory facilities. Economic analysis of cost-benefit. More accurate methodologies needed	Incentive programme to animal productivity.	
	Mineral and salt supplementation.	CH_4 N_2O	CH_4: Not estimated N_2O: 5–10 %				Potential environmental and human health effects of mineral residues.

Table 28 (continued)

Practices	Sub-group of practices	Gases affected	Relative mitigation potential (unit of production, others)	Methodologies to estimate emissions (other relevant elements to measure, report and verify)	Challenges/ barriers, feasibility, including information on cost-opportunity and cost-effectiveness (whenever possible)	Co-benefits and contribution to sustainable development	(Environmental) risks/impacts
Dietary additives and specific agents	Ionosphores, probiotics and propionate precursors.	CH_4	*Dairy Cows:* 0.3–8 % *Beef Cattle:* 0.4–9 % *Sheep:* 0.02–0.4 % *Dairy Buffaloes*: 1–3 % *Non-Dairy Buffaloes:* 0.4–1.2 %	Emission Factors by experimental measurements. Tier 2 to estimate emissions (2006 IPCC Guidelines, Vol.4, Ch. 10)	Uncertain if reduction responses are sustained in time. Main barriers are: Research and laboratory facilities. Commercial availability of products Regulatory framework (regulations on some products need it). Technology transfer needed.	CH_4 emission reduction, as co-benefit of improving animal performance. Compatible with sustainable development. Higher profitability in production systems of animal products.	Potential environmental and human health effects of dietary additives and other supplemented specific agents.

Table 28 (continued)

Practices	Sub-group of practices	Gases affected	Relative mitigation potential (unit of production, others)	Methodologies to estimate emissions (other relevant elements to measure, report and verify)	Challenges/ barriers, feasibility, including information on cost-opportunity and cost-effectiveness (whenever possible)	Co-benefits and contribution to sustainable development	(Environmental) risks/impacts
	Use of *Ionophores*	CH_4	All livestock: maximum 20 % CH_4 in vitro: 21–25 % CH_4 in field: Variable results				
	Use of *Probiotics*	CH_4	CH_4 for dairy beef: ± 7 % CH_4: 8–50 %				
	Use of *Propionate precursors*	CH_4	CH_4: 24–28 %				
Hormone and enzyme manipulation	Use of Bovine somatotropin (bST) and hormonal growth implants	CH_4	Reduction of N_2O and CH_4: For bST 15 % For other hormones and enzymes not estimated.		Main barriers: Reluctance of consumers to buy due to the presence of hormone residues. Substances used for hormone manipulation is illegal in some countries. Costs involved.	CH_4 emission reduction, as co-benefit of improving animal performance. Compatible with sustainable development. Higher profitability in production systems of animal products.	Possible effects on human health of hormone residues in foods and natural resources (such as drinking water)

Table 28 (continued)

Practices	Sub-group of practices	Gases affected	Relative mitigation potential (unit of production, others)	Methodologies to estimate emissions (other relevant elements to measure, report and verify)	Challenges/ barriers, feasibility, including information on cost-opportunity and cost-effectiveness (whenever possible)	Co-benefits and contribution to sustainable development	(Environmental) risks/impacts
Pasture management	Stocking rate and rotational grazing. Species introduction. Nitrogen fertilization, fire management and improvement of topsoil physical conditions	CH_4 CO_2 NO_2 (*)	CO_2: 0.11–0.81 CH_4: 0.02 All: 0.13–0.81 (units: t CO_2 eq ha^{-1} yr^{-1})	Enteric emissions: Tier 2 for Emission Factors and emissions (2006 IPCC Guidelines, Vol.4, Ch.10). Soils N_2O emissions: 2006 (2006 IPCC Guidelines, Vol.4, Ch.6, Grasslands)	No technological barriers. Main barrier is the cultural background of farmers and the availability of certain inputs (for example selected seeds). Economic incentives, information and technology transfer are needed	Compatible with sustainable development. Improving the environmental sustainability of pastures. Reducing soil erosion and desertification. Increasing carbon sequestration (soils and biomass).	Potential environmental effect on the natural flora composition of introduced plant species.

Table 28 (continued)

Practices	Sub-group of practices	Gases affected	Relative mitigation potential (unit of production, others)	Methodologies to estimate emissions (other relevant elements to measure, report and verify)	Challenges/ barriers, feasibility, including information on cost-opportunity and cost-effectiveness (whenever possible)	Co-benefits and contribution to sustainable development	(Environmental) risks/impacts
Pasture management (continued)	*Stocking rate and rotational grazing*	CH_4 CO_2	Not estimated				
	Species introduction	CO_2 NO_2 (*)	Maximum 20 % from new forage cultivars				
	Nitrogen fertilization and fire management	CO_2 NO_2	NO_2: 5 % CO_2: Reduction not estimated				
	Improvement of topsoil physical conditions	CO_2 NO_2	N_2O: 7–11 %				
	Including physical treatment of forage and plant breeding programmes	CH_4 N_2O (*)	Not estimated		More accurate methodologies needed. Incentives and programmes to improve animal productivity are needed.		

Table 28 (continued)

Practices	Sub-group of practices	Gases affected	Relative mitigation potential (unit of production, others)	Methodologies to estimate emissions (other relevant elements to measure, report and verify)	Challenges/ barriers, feasibility, including information on cost-opportunity and cost-effectiveness (whenever possible)	Co-benefits and contribution to sustainable development	(Environmental) risks/impacts
Manure management for CH_4 reduction	Biogas collection and use, aerobic treatment and application.	CO_2 CH_4	CO_2: 1.54–2.79 N_2O: Non estimated All: 1.54–2.79 (units: t CO_2 eq ha^{-1} yr^{-1})	Tier 1 (2006 IPCC Guidelines Vol. 4, Ch. 10)	The lack of appropriate incentives and information may be the main barrier. There is a lack of a network of enterprises and experts who give support to biogas technology. Lack of legal background. Technology transfer and incentive programmes are needed.	Win-win option. Substitution of fossil fuels. Increasing the profitability of the system.	Possible increase in N_2O emissions arising from digestates application to soils and possibly nitrate leaching.
	Collecting CH_4 in closed environments and burning.		CH_4: 90 % NO_2: Non estimated				
	Collecting CH_4 in biodigestors and using as biogas		CH_4: 90 % NO_2: uncertain				
	Aerobic treatment (composting, co-composting, aerobic waste treatment, soil application)	CH_4, NO_2	10–35 %				

Table 28 (continued)

Practices	Sub-group of practices	Gases affected	Relative mitigation potential (unit of production, others)	Methodologies to estimate emissions (other relevant elements to measure, report and verify)	Challenges/ barriers, feasibility, including information on cost-opportunity and cost-effectiveness (whenever possible)	Co-benefits and contribution to sustainable development	(Environmental) risks/impacts
Manure management for nitrous oxide reduction	Effluent management: Mechanical separation of solids and liquids	CH_4	N_2O: 15 % CH_4: increase N/E CO_2: increase N/E	Option 1: parameters from field measurements; then tier 2. Option 2: tier 3 (2006 IPCC Guidelines, V4, Ch10)	Essentially, no technological barrier. The lack of appropriate incentives and environmental regulations may be the main barriers . Technology transfer, information and incentives programmes are needed.		The correct disposal of effluents is essential
	Optimal soil application of animal manures: Nitrogen amount, form, timing of application	N_2O	NO_2: 2–10 % CH_4: increase N/E N_2O: 50 %	Soils N_2O emissions: 2006 IPCC Guidelines, V4, Ch6 (Grassland)	Implemented with the current technology available. Technology transfer and economic incentives are needed	Win-win options Reduces groundwater pollution. Reduces soil erosion. Improves the profitability of the system	Increasing risk of groundwater pollution if liquid manure applications are not optimized

(*) Emissions may be reduced.

Source: IPCC. 2007b. *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge, United Kingdom and New York, New York, United States.

Annex III

Table 29. Future mitigation practices: information gaps and future needs

Practice	Practices included	Gas abated	Relative mitigation potential (per unit of production, others)	Information gaps and implementation needs	Research and development, and technological cooperation and needs	Risk and/or impacts
High performance animals	Cloning and genetic manipulation techniques	CH_4 N_2O	Not estimated for CH_4 or N_2O	National regulations. Research and laboratory facilities.	Biotechnology research programmes.	Potential environmental effects of transgenic material.
Dietary additives and specific agents	Changing rumen micro flora activity: Use of bacteriocins, halogenated compounds, chloroform, vaccine against methanogens, and other CH_4 producer inhibitors.	CH_4	Homogenate compounds: 54 % Saponins: Not estimated Nisin: 36 % Immunisation up to 70 % Vaccines: 11–23% Other inhibitors: 17–100 % Bovicin HC5 in vitro: 50 %	Sustainability of animal responses to the practice, not yet well understood. Environmental effects of animal residues.	Sustainability of animal responses to the practice and environmental effects of residues released into the environment. Technology transfer from developed countries.	Potential environmental and human health effects of residues released to the environment or in human foods.
	Strategic supplementation (MUB or MNBs).	CH_4	15–25 % in field and 35–40 % in vitro		Technology transfer. Adaptation to local conditions.	
	Changing rumen micro flora composition: Including phage therapy, acetogens, CH_4-oxidizing bacteria.	CH_4	Oxidizing bacteria: 8 % Acetogens: high mitigation level	Biological research and laboratory facilities.	Local production of commercially available products.	Potential environmental effects of residues released to the environment.

Table 29 (continued)

Practice	Practices included	Gas abated	Mitigation potential (relative) (unit of production, others)	Information gaps and implementation needs	Research and development, and technological cooperation and needs	(Environmental) Risk/impacts
Pasture management	Adoption of crop-livestock-forestry integration system.	CH_4 N_2O CO_2	Not estimated	Biological research and laboratory facilities.	Research in progress.	
Manure management for CH_4 reduction	Manure cooling.	CH_4	Not estimated	Global assessment of impacts on greenhouse gas emissions during the life cycle of manure.	No special technological developments are needed.	Possible increase in the use of fossil fuels.
Manure management for nitrous oxide reduction	Covering manure piles or lagoons.	N_2O	90 % reduction	Extent of reduction effects.		
	The use of nitrification inhibitors for soils and manures.	N_2O	Not estimated	Responses under different agro ecological conditions. Nitrification inhibitors are expensive, but the reduction in mineral fertilizer requirements through reduced nitrogen losses may offset this cost.	Research in progress.	
	Diet manipulation to increase acid hippuric content.	N_2O	50 % reduction	Unknown	Research in progress.	Unknown

Annex IV

Table 30. Current mitigation practices in crops and soils

Practice	Relative mitigation potential (unit of production)	Methodologies to estimate emissions (other relevant elements to measure, report and verify)	Challenges/barriers (policy, poverty, knowledge, extension)	Opportunities (feasibility, cost-effectiveness, synergy with adaptation)	Co-benefits and contribution to sustainable development
Cropland management: Agronomy	Soil carbon increase: 0.2–0.88 t CO_2 ha^{-1} yr^{-1} (mean ranges) Direct N_2O: 0.10 t CO_2 eq ha^{-1} yr^{-1}	2006 IPCC Guidelines, Volume 4, Chapter 5 (Cropland), and Chapter 11 (N_2O Emissions from Managed Soils).	The practice involves the use of improved varieties (e.g. GMO), and crop rotations (with perennial crops, legumes, etc) that may challenge consistency with traditional practices.	Adopting cropping systems with reduced reliance on fertilizers and other inputs is an opportunity to explore for better economic returns.	Increases productivity (food security) improves soil quality and enhances the conservation of other biomes.
Cropland management: Nutrient management	Soil carbon increase: 0.26–0.55 t CO_2 ha^{-1} yr^{-1} (mean ranges) Direct N_2O: 0.07 t CO_2 eq ha^{-1} yr^{-1}	2006 IPCC Guidelines, Volume 4, Chapter 5 (Cropland), and Chapter 11 (N_2O Emissions from Managed Soils).	This practice includes precision farming and the use of slow-release fertilizer that may be costly to implement. Other challenge it would be technology transfer, diffusion and deployment.	Precise application of nitrogen fertilizer makes it more accessible to crop roots, which means more yields at less input.	Improves the quality of soil, water and air quality and promotes energy conservation.
Cropland management: Tillage and/or residue management	Soil carbon increase: 0.15–0.70 t CO_2 ha^{-1} yr^{-1} (mean ranges) N_2O: 0.02 t CO_2 eq ha^{-1} yr^{-1}	2006 IPCC Guidelines, Volume 4, Chapter 5 (Cropland), and Chapter 11 (N_2O Emissions from Managed Soils).	This practice requires advances in weed control methods and farm machinery and avoid burning of crop residues. Chemical weed control may be against environmental policies.	Reduced tillage can reduce the use of fossil fuel thus less CO_2 emissions from energy use.	Increases productivity (food security); improves soil quality; promotes water and energy conservation, and supports biodiversity and wildlife habitat.

Table 30 (continued)

Practice	Relative mitigation potential (unit of production)	Methodologies to estimate emissions (other relevant elements to measure, report and verify)	Challenges/barriers (policy, poverty, knowledge, extension)	Opportunities (feasibility, cost-effectiveness, synergy w/ adaptation)	Co-benefits and contribution to sustainable development
Cropland management: Water management (irrigation and drainage)	Soil carbon increase: $1.14\ t\ CO_2\ ha^{-1}\ yr^{-1}$ (average)	2006 IPCC Guidelines, Volume 4, Chapter 5 (Croplands).	Expanding irrigation areas or using more effective irrigation measures entail requires resources. Some gains from this practice may be offset by emissions from energy used to supply the water.	More effective irrigation measures that use less fuel could be explored.	Promotes productivity (food security) and the conservation of other biomes.
Cropland management: Rice management	CH_4: 7–63 % in continuously flooded rice fields with organic amendment; 7–46 % in midseason drained rice fields with no organic amendment; and 9–80 % in continuously flooded rice fields with no organic amendment.	2006 IPCC Guidelines, Volume 4, Chapter 5 (Croplands).	The benefit of CH_4 emission reductions may be offset by the increased of N_2O emissions, and the practice may be limited by the water supply.	More effective rice straw management to reduce CH_4 emissions (e.g. to be used as biofuels).	Promotes productivity (food security) and the conservation of other biomes and improves water quality.

Table 30 (continued)

Practice	Relative mitigation potential (unit of production)	Methodologies to estimate emissions (other relevant elements to measure, report and verify)	Challenges/barriers (policy, poverty, knowledge, extension)	Opportunities (feasibility, cost-effectiveness, synergy w/ adaptation)	Co-benefits and contribution to sustainable development
Cropland management: Agroforestry	Tree biomass carbon increase: 1- t CO_2 ha^{-1} yr^{-1}. Soil carbon increase: 0.15–0.70 t CO_2 ha^{-1} yr^{-1}. N_2O: 0.02 t CO_2 eq ha^{-1} yr^{-1}.	2006 IPCC Guidelines, Volume 4, Chapter 4 (Forest Land), Chapter 5 (Cropland), and Chapter 11 (N_2O Emissions from Managed Soils).	The effects on N_2O and CH_4 emissions are not well understood. The fate of harvested wood products has to be taken into account.	Harvest from trees (fuel wood) could be used for bioenergy. Additional returns for farmers.	Promotes biodiversity wildlife habitat, energy conservation, and in some cases poverty reduction.
Cropland management: Set-aside, and land-use change	Soil carbon increase: 1.61–3.04 t CO_2 ha^{-1} yr^{-1} CH_4: 0.02 t CO_2 eq ha^{-1} yr^{-1} N_2O: 2.30 t CO_2 eq ha^{-1} yr^{-1}	2006 IPCC Guidelines, Volume 4, Chapter 5 (Cropland), and Chapter 11 (N_2O Emissions from Managed Soils).	Cropland conversion reduces the number of areas intended for food production.	Usually only an option for surplus agricultural land or on croplands of marginal productivity.	Improves the soil, water and air quality, promotes water and energy conservation, and supports biodiversity, wildlife habitat and the conservation of other biomes.

Table 30 (continued)

Practice	Relative mitigation potential (unit of production)	Methodologies to estimate emissions (other relevant elements to measure, report and verify)	Challenges/barriers (policy, poverty, knowledge, extension)	Opportunities (feasibility, cost-effectiveness, synergy w/ adaptation)	Co-benefits and contribution to sustainable development
Grassland management: Grazing, fertilization, fire practices	Soil carbon increase: 0.11–3.04 t CO_2 ha $^{-1}$ yr $^{-1}$ CH_4: 0.02 t CO_2 eq ha $^{-1}$ yr $^{-1}$	2006 IPCC Guidelines, Volume 4, Chapter 6 (Grassland)	Nutrient management and irrigation may increase energy use. The introduction of species may have an ecological impact.	Improves productivity.	Grazing intensity improves soil quality, promotes biodiversity and wildlife habitat; and enhances aesthetic and/or amenity value Nutrient management increases productivity (food security), improves soil quality, promotes water conservation and conservation of other biomes, and supports biodiversity and wildlife habitat. Fire management increases productivity (food security), and improves air and water quality.

Table 30 (continued)

Practice	Relative mitigation potential (unit of production)	Methodologies to estimate emissions (other relevant elements to measure, report and verify)	Challenges/barriers (policy, poverty, knowledge, extension)	Opportunities (feasibility, cost-effectiveness, synergy w/ adaptation)	Co-benefits and contribution to sustainable development
Restoration of organic soils	Soil carbon increase: 36.7–73.3 t CO_2 ha $^{-1}$ yr $^{-1}$ N_2O: 0.16 t CO_2 eq ha $^{-1}$ yr $^{-1}$	Methodology for further development (see 2006 IPCC Guidelines Volume 4, Chapter 7 (Wetlands)	No available compilation of the global area of wetland restoration and construction; need better knowledge of the processes involved to avoid double counting.	Avoiding row crops and tubers, avoiding deep ploughing and maintaining a shallower table are strategies to be explored.	Improves soil quality and aesthetic and/or amenity value and promotes biodiversity, wildlife habitat and energy conservation.
Restoration of degraded lands	Soil carbon increase: 3.45 t CO_2 ha $^{-1}$ yr $^{-1}$ (average) CH_4: 0.08 t CO_2 eq ha $^{-1}$ yr $^{-1}$	2006 IPCC Guidelines, Volume 4, Chapter 5 (Croplands), and Chapter 6 (Grasslands)	Where this practice involves higher nitrogen amendments, the benefit of carbon sequestration may be partly offset by higher N_2O emissions.		Increases productivity (food security) improves soil and water quality and the aesthetic and amenity value and supports biodiversity, wildlife habitat, and the conservation of other biomes.

Table 30 (continued)

Practice	Relative mitigation potential (unit of production)	Methodologies to estimate emissions (other relevant elements to measure, report and verify)	Challenges/barriers (policy, poverty, knowledge, extension)	Opportunities (feasibility, cost-effectiveness, synergy w/ adaptation)	Co-benefits and contribution to sustainable development
Bioenergy (soils only)	Soil carbon increase: 0.15–0.70 t CO_2 ha^{-1} yr^{-1} N_2O: 0.02 t CO_2–eq ha^{-1} yr^{-1}	2006 IPCC Guidelines, Volume 4, Chapter 5 (Cropland), Chapter 6 (Grasslands), and Chapter 11 (N_2O Emissions from Managed Soils)	Competition for other land uses and impact on agro ecosystem services such as food production, biodiversity and soil moisture conservation.	Technical potential for biomass. Technological developments in converting biomass to energy.	Promotes energy conservation.

Source: IPCC. 2007b. *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmetal Panel on Climate Change* (, *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Published by the Institute for Global Environmental Strategies (IGES) for the IPCC. ISBN 4-88788-032-4. Available in <http://www.ipcc.ch/ipccreports/methodology-reports.htm>;
Wassmann R, Lantin RS, Neue HU, Buendia LV, Corton TM, and Lu Y. 2000. *Characterization of Methane Emissions from Rice Fields in Asia*. III. Mitigation Options and Future Research Needs. Nutrient Cycling in Agroecosystems 58: pp.23–36; DEFRA, 2007. *A review of research to identify best practice for reducing greenhouse gases from agriculture and land management*. Defra Project AC0206, London, United Kingdom; Setyanto P, Mulyadi, and Zaini Z. 1997. *Emisi gas N_2O dari beberapa sumber pupuk nitrogen di lahan sawah tadah hujan*. Journal Penelitian Pertanian Tanaman Pangan 16: pp.14–18.

Annex V

Table 31. Future mitigation practices: gaps and future needs

Practice	Relative mitigation potential (unit of production, others)	Information gaps and information needs	Research and development, and technological cooperation and needs
Reduced and/or zero tillage	Soil carbon increase: 0.59 t CO_2 eq ha^{-1} yr^{-1} from reduced tillage and 1.13 t CO_2 eq ha^{-1} yr^{-1} from zero tillage Indirect N_2O: Decrease nitrated leaching by 0–5 kg N ha^{-1}	The overall greenhouse gas balance of reduced/zero tillage systems needs to be evaluated to assess where soil carbon storage increases are outweighed by enhanced N_2O emissions.	There is limited evidence that reduced/no tillage results in a greater soil water holding capacity and hence results in increased direct N_2O emissions.
Use of nitrification inhibitors	Can reduce nitrate leaching by up to 35 %.	Nitrification inhibitors are expensive and this may prevent farmers from using them, but the reduction in mineral fertilizer requirements through reduced nitrogen losses may offset this cost.	There is a need to quantify the potential benefits of nitrification inhibitor use to mitigate N_2O emissions and to assess potential benefits in terms of increased nitrogen use efficiency (i.e. synchrony with crop needs) and water quality (nitrate leaching) improvements.
Improved mineral fertilizer nitrogen timing strategies	Could be highly effective if better nitrogen use efficiency is achieved, nitrate leaching losses are also likely to be reduced.	The method depends on development of farmer friendly site-specific tests or forecasts.	Underpinning knowledge and predictive forecasting approaches to the timing of mineral fertilizer nitrogen applications to minimize N_2O losses is lacking.

Table 31 (continued)

Practice	Relative mitigation potential (unit of production, others)	Information gaps and information needs	Research and development, and technological cooperation and needs
Use of plants with improved nitrogen use efficiency	This method would be directly effective in reducing N_2O emissions from soil It may also have secondary benefits for forage crops in reducing the amount of nitrogen excretion from grazing animals, if used in conjunction with feed plans for improved rumen capture of nitrogen. Also, if better nitrogen use efficiency is achieved, nitrate leaching losses are likely to be reduced.	Depends on the existence of high nitrogen use efficiency plants with seed at cost effective prices and no accompanying management or food quality detriments.	Research and development activity to improve the nitrogen use efficiency of crops
Production of natural nitrification inhibitors by plants	It could reduce N_2O emissions and thereby increase the efficiency of the utilization of applied nitrogen.	Some. The incorporation of plants that produce natural nitrification inhibitors in their roots into arable and forage crops would reduce N_2O emissions from applied fertilizers and manures. Genetic modification is one potential route for the introduction of this trait, although the public is likely to be against this.	The discovery of native plants, with natural nitrification inhibitors properties that are close enough taxonomically to commercially important crops, may make it possible for conventional breeding techniques to be used.

Source: DEFRA, 2007. *A review of research to identify best practice for reducing greenhouse gases from agriculture and land management*. Defra Project AC0206, London, United Kingdom.