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# Challenges and opportunities for mitigation in the agricultural sector

**Technical paper**

*Summary*

This paper provides an overview of mitigation practices for the agricultural sector, and identifies relevant policies and measures (PAMs). It addresses the relative mitigation potential of each mitigation practice presented, as well as methodological and technical challenges, and possible barriers for their implementation.

The paper also identifies win-win options, best practices and co-benefits and synergies for each practice. Knowledge gaps and research and development needs on mitigation practices are identified as the basis of recommendations for future work.

Background information on emissions, trends and projections in relation to livestock, and crops and soils are also presented in the paper. The paper aims to contribute to the better understanding of the challenges and opportunities for mitigation in the agricultural sector, with consideration of the regional and national circumstances for the feasibility and applicability of the mitigation practices. The information may be taken into account by Parties when considering the role, potential and challenges of the agricultural sector for mitigating climate change in support of the upcoming discussions under the Ad-Hoc Working Group on Long-Term Cooperative Action under the Convention (AWG-LCA), including the in-session workshop to be held during the fifth session of the AWG-LCA in 2009.

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# I. Executive summary

1. In response to a request by the Ad Hoc Working Group on Long-term Cooperative Action under the Convention (AWG-LCA), at its second session, the secretariat has prepared this technical paper on challenges and opportunities for mitigation in the agriculture sector. The paper draws on information included in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (AR4), national greenhouse gas (GHG) inventories and national communications submitted by Parties to the Convention, as well as other relevant publications.

### A. Emissions and trends

2. Agriculture provides the primary source of livelihood for more than one third of the world's total workforce, who produce the food needed to sustain the population of our planet. At the same time, agricultural activities are responsible for the release of significant amounts of carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$) into the atmosphere. These three GHGs are chemically stable, long-lived gases that have a long-term influence on the global climate.

3. Agriculture contributes 10–12 per cent of the total global anthropogenic GHG emissions or about 6.8 Gt of $CO_2$ equivalent (eq) per year. Between 1990 and 2005, emissions from the sector increased by about 17 per cent and are projected to increase further in the coming decades due to expected increases in food demand and diet changes as the global population continues to grow.

4. On a global scale, the **main sources** of non-$CO_2$ GHG emissions from agriculture are: soils ($N_2O$ emissions), enteric fermentation ($CH_4$ emissions), manure management ($CH_4$ and $N_2O$ emissions) and rice cultivation ($CH_4$ emissions). In 2005, regional emissions were highest in South and Southeast Asia and Latin American countries, reflecting national, environmental, social and technological circumstances. GHGs from land-use change, including deforestation in tropical areas, are (in most countries) associated with agricultural activities and exceed emissions from all other agricultural sources.

### B. Mitigation potential and costs

5. The global technical mitigation potential[1] of agriculture, excluding fossil fuel offsets from biomass, by 2030 is estimated to be 5.5–6 Gt $CO_2$ eq per year. About 89 per cent of this potential can be achieved by **soil carbon (C) sequestration** through cropland management, grazing land management, restoration of organic soils and degraded lands, bioenergy and water management. **Mitigation of $CH_4$** can provide an additional 9 per cent through improvements in rice management, and in livestock and manure management. The remaining 2 per cent can be achieved from **mitigation of $N_2O$** emissions from soils mainly through crop management.

6. The economic potential[2] in 2030 is estimated to be: 1.5–1.6 Gt $CO_2$ eq per year (C price: USD 20t $CO_2$ eq); 2.5–2.7 Gt $CO_2$ eq per year (C price USD 50 per t $CO_2$ eq); and 4–4.3 Gt $CO_2$ eq per year (C price: USD 100 t $CO_2$ eq). About 30 per cent of this potential can be achieved in developed countries and 70 per cent in developing countries.

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[1] 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 been demonstrated already. No explicit reference to costs is made but adopting 'practical constraints' may take into account implicit economic considerations (IPCC AR4).

[2] 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) (IPCC AR4).

7. The technical mitigation potential reflects the possibility of reducing GHG emissions through the implementation of technological improvements and innovations, whereas the economic mitigation potential reflects the possible GHG reductions taking into account the influence of market conditions, including carbon prices. For agriculture, the materialization of the full mitigation potential is a complex issue.

8. Relative potentials associated with different mitigation practices are provided in tables 28, 29 and 30. These tables can be used to compare the effectiveness of these practices and as a tool for the design and assessment of national portfolios of mitigation strategies that need to take into account national circumstances and how they relate to the evolution of the agriculture sector, as well as the impacts of existing and planned policies.

### C. Present emission abatement strategies

9. Reductions in **$CH_4$ emissions from enteric fermentation** can be achieved through the improvement of animal performance. This can be achieved by either improving the diet quality (feeding practices and pasture management) or having more efficient animals (high genetic merit animals).

10. The release of **$CH_4$ and $N_2O$ emissions from manure management** is the result of different microbiological processes. Efforts invested in abating one gas normally alters the emissions of the other gas, thus requiring a comprehensive assessment for any mitigation strategy. Reductions of $CH_4$ emissions can be achieved by promoting aerobic processes (composting, aerobic waste treatment systems) or by recycling – as biogas – the $CH_4$ produced under anaerobic conditions. $N_2O$ emission reductions can be achieved by changing feeding practices, using better practices to apply manure to soils, and the use of nitrification inhibitors.

11. **Pasture management** has the potential to improve the animal diet, leading to reductions of enteric fermentation emissions and to maintain/increase C storage in soil and biomass. Many management measures to improve grazing animal performance (forage amount/quality, grazing practices, pasture productivity) will affect C sequestration positively. Improving pasture management practices will also induce additional environmental and social co-benefits such as increased environmental sustainability and maintenance of local biodiversity. Given that natural grasslands are about 70 per cent of the world's agricultural lands, the technical mitigation potential of grazing management is largely higher than enteric or manure management emissions and can be implemented in all countries. Compared to other types of land-use change and compared to a number of management options, **improved grazing land management and agroforestry** offer the highest potential for C sequestration in developing countries (about 60 per cent of the grazing lands available for C sequestration are in these countries).

12. Reduced or no tillage, use of nitrification inhibitors and optimum amount and timing of fertilizer application could result in reduced **GHG emissions from soils,** while it can lead to an **increase in organic C stored in soils**. Approximately 15 per cent of the global emissions from croplands (soils) can be mitigated at a net benefit or at no cost (less than USD 0 per t $CO_2$ eq) and 20–23 per cent for less than USD 30 per t $CO_2$ eq.

13. Water management and waste residue management offer opportunities for the mitigation of **$CH_4$ emissions from rice cultivation**. However, water management strategies to reduce $CH_4$ emissions through drainage usually increase $N_2O$ emissions, particularly in heavily fertilized systems. Approximately 3 per cent of the global emissions from rice cultivation could be mitigated at no cost. At a price of USD 30 per t $CO_2$ eq, the mitigation potential increases to 13 per cent.

14. Effective means for reducing **emissions associated with conversion of land** to agriculture is through intensification of agriculture, that is, by producing more on land already in production, through for example increased stocking rate associated with pasture fertilization, greater pasture utilization

associated with introduction of legumes, more efficient grazing rotation, crop rotations and using more productive crops.

15. **Energy-related emissions** from agriculture are a relatively small source contributing to about 11 per cent of the total non-$CO_2$ GHG emissions from the sector. In South and Southeast Asia, where energy-related emissions are highest, biodiesel and electricity generation with renewable energy sources offer meaningful opportunities to reduce emissions.

### D. Possible future mitigation practices

16. Future options for reducing emissions from enteric fermentation include: strategic supplementation; rumen ecology manipulation by changing microflora activity or microflora composition; use of advanced animal breeding and cloning techniques; genetic manipulation to obtain more efficient animals; and livestock housing with suitable technologies to capture and separate $CH_4$.

17. Future mitigation options for manure management include: manure cooling to avoid $CH_4$ formation; manure cover to avoid release of nitrogen (N); use of nitrification inhibitors, both in soils and manure piles; advanced anaerobic digestion technologies for enhanced nutrient recycling and renewable energy production.

18. For crops and soils, future mitigation options include: use of nitrification inhibitors; use of plants with improved N use efficiency; production of natural nitrification inhibitors by plants; improved management of wet and organic soils; and use of agriculture fertilizing precision techniques.

19. For all of the above future mitigation options, further research and development is required before they can become commercially available.

### E. Case studies

20. A number of case studies that provide information on national experiences are presented in this technical paper. Some highlights of the information presented are:

(a) Despite differences in cattle production systems around the world, the main mitigation measures are linked to pasture improvement, forage supplementation and increased adoption of feedlots. In some cases, the use of feed additives (such as ionosphores) has proved to be a cost-effective mitigation measure;

(b) Advances have been made in the use of biogas from dairy, beef and swine manure in different countries. However differences exist in how this measure is being implemented. Examples are given of a nationally driven approach and an approach that has been promoted under the clean development mechanism (CDM);

(c) Enhancing the implementation of measures to improve forage availability and quality can be achieved through the integration of such measures in national development policies that include forage yield recovery goals;

(d) Reducing emissions associated with conversion of land to cropping can be achieved through agriculture intensification, provided this is achieved in a sustainable way without significant additional inputs of fertilizer and energy. Over the last five decades, significant technological developments have resulted in new varieties of crops with increasing yields. The use of these new crop varieties has resulted in reduced land-use change and associated emissions;

(e) C sequestration in grasslands and agroforestry plantations have significant potential for C reductions from the agriculture sector at non-prohibitive costs.

### F. Measuring, reporting and verifying emissions

21. For all present mitigation strategies/approaches listed in this technical paper, the tiers of the IPCC methodology can be used to estimate emissions and relative reductions. Depending on the strategy employed, simple tier 1 or more complex tier 2 and tier 3 methods can be used.

22. Estimations of emissions and sinks of GHGs resulting from the implementation of the broad spectrum of mitigation measures included in the paper have associated uncertainties that will be difficult to reduce, even when applying the best available methods. Relatively high uncertainty associated with the above estimations needs to be carefully considered and managed, but should not become an additional barrier for the implementation of mitigation measures in the sector because emission reductions can be estimated with the methodologies included in the IPCC guidance.

23. Estimations of emissions and sinks of GHGs need to be reported and reviewed for assessing the effectiveness of agricultural measures and policies to mitigate GHG emissions. The paper builds upon data and methodological guidance already made available by the IPCC and the national GHG inventories under the UNFCCC process. Methodological and reporting guidance, and procedures to review emissions and sinks from agriculture have already been implemented successfully in the context of the UNFCCC process in many national GHG inventories and CDM projects. These can serve as a basis for the discussions on ways to measure, report and verify the estimates associated with the agricultural practices addressed in this paper.

### G. Policies and measures

24. In order to ensure maximum efficiency of mitigation actions in agriculture, it would be appropriate to consider a systemic approach, taking into account all aspects of agricultural systems (as well as the interactions between them) including co-benefits (e.g. forage improvements to increase animal productivity could result in reductions of enteric $CH_4$ emissions) and trade-offs (e.g. increasing fertilizer to increase productivity and soil carbon storage may increase emissions of $N_2O$ and $CH_4$). Such co-benefits and trade offs would play an important role in the decision-making process regarding the selection of appropriate policies and measures at the national or regional level.

25. Establishing **policies** for GHG reductions from agriculture can be accomplished through national policies and international agreements. Four key areas to consider when establishing policies on mitigation in agriculture are: full GHG accounting; measurement of sequestration and emission rates; permanence; and enabling conditions for the adoption of practices.

26. **Measures** for reducing GHG emissions from the agriculture sector include: market-based programmes, regulatory measures, voluntary agreements and international programmes. Examples of market-based programmes are the reduction and reform of agricultural support policies; taxes on the use of N fertilizers; emissions trading; and subsidization of production. Regulatory measures could include limits or guidance on the use of N fertilizers; improved fertilizer manufacturing practices; and cross-compliance of agricultural support to environmental objectives. Voluntary agreements could involve soil management practices that enhance C sequestration in agricultural soils. International programmes could support technology transfer in agriculture.

27. In some cases, non-climate policies have had an impact on emissions from agricultural activities through international/regional cooperation. Examples include the European Union (EU) common agricultural policy (CAP), the EU Nitrates Directive, the Methane to Markets Partnership and the Livestock Emissions and Abatement Research Network.

28. There are limitations to emissions reductions in the agriculture sector particularly because of the role of the sector in providing food for a global population that is expected to continue to grow in the coming decades. Therefore, it would be reasonable to expect emissions reductions in terms of

improvements in efficiency rather than absolute reductions in GHG emissions. Such mitigation efforts could offer opportunities for enhancing sustainable development and food security and contribute towards poverty alleviation in developing countries.

29. There is no one size fits all when considering which measures to be implemented at the national level. Each country would have to decide on key issues for its mitigation strategy portfolio, recognizing its national environmental, social and economic circumstances. Synergy between climate change policies, sustainable development and improvement of environmental quality would provide additional incentives to promoting and realizing the mitigation potential of policies and measures in agriculture.

30. Generally, farmers are open to adopting practices that could lead to an increase in profits and/or productivity. Given the indirect co-benefit of reducing GHG emissions, the adoption of such measures could be promoted through national educational and dissemination programmes that raise awareness, in particular via greater use of agricultural extension services.

## H. Challenges and barriers

31. Aspects that can make less attractive or discourage the adoption of mitigation activities in the agriculture sector include: the limit or the maximum capacity of soils to store C; the risk of losing C stored (e.g. because of a change in soil C management); difficulties in establishing a baseline, which is the basis of assessing emission reductions, due to the lack of the information needed in some countries or regions; high uncertainty in emissions estimates and lack of information for their assessment. Other barriers include high transaction costs, concerns about competitiveness, in some cases relatively high measurement and monitoring costs for emission reductions, availability of investment capital, slow progress in technological development, and breaking from traditional practices.

32. In many regions, non-climate policies related to macroeconomics, agriculture and the environment have a larger impact on agricultural mitigation than climate policies. Overcoming barriers to implementation is likely to require policy and economic incentives and other programmes, such as promoting global sharing of innovative technologies. For livestock production, technology transfer may be more accessible than in other sectors (for example industry), except when dealing with highly efficient animals.

33. Government spending patterns will need to be adjusted to reflect changed priorities if mitigation practices are to be promoted in the sector. For example in developed countries government expenditures for agriculture are generally about 20 per cent of the national gross domestic product (GDP), while in developing countries they average less than 10 per cent.

## I. Recommendations for future work

34. Synergies between agriculture-related climate change policies and sustainable development, food security, energy security and improvement of environmental quality need to be identified in order to make agricultural mitigation practices attractive and acceptable to farmers, land managers, and policymakers. Given that production systems rely on climatic conditions and the use of natural resources (for example, soils and water), any specific mitigation option must be assessed comprehensively in order to understand the links between all the system components and the emissions of all GHGs.

35. It would be desirable:

(a) To make broadly accessible to farmers, land managers and policymakers methods for verifying and validating GHG emission reductions from agricultural activities, and further develop methods for comparing the effectiveness of various mitigation options;

(b) To develop and make accessible comprehensive assessment tools (for use prior to the implementation of mitigation options) in order to gain a better understanding of the GHG emission reductions and of the associated environmental, economic and social benefits and impacts for the overall production cycle;

(c) To address technological and financial barriers associated with the use of agricultural wastes, including the potential to convert them into commercial fuels;

(d) To link research to the development of decision support tools and policy options.

### J. Possible issues for further consideration

36. When considering mitigation in the agriculture sector within the context of the AWG-LCA, other elements addressed by the Bali Action Plan may have to be considered. Such elements include: technology transfer and/or dissemination, investment and financial needs for the implementation of available and future practices; and the need for capacity-building to enable developing countries to implement relevant mitigation strategies and programmes, as well as research and development.

37. During the deliberations under the AWG-LCA, some Parties have proposed that agriculture could be a candidate for the implementation of cooperative sectoral approaches and sector-specific actions to enhance implementation of Article 4, paragraph 1 (c), of the Convention. Within this context, Parties may wish to focus their discussions on the mitigation of emissions from the agriculture sector, by identifying:

(a) Priority mitigation activities for the agriculture sector, taking into account the information provided in this technical paper;

(b) Links between actions at the national, regional and global levels. Given the current structure of the agriculture sector, which involves all developed and developing countries as both producers and consumers of agricultural products, it would be important to consider how opportunities for regional cooperation, sectoral agreements and nationally driven actions can contribute to (or fit under) a global agreement on climate change;

(c) The level of resources needed and the mechanisms required for mobilizing these resources to ‘green’ agricultural production, while ensuring the sustainable development of the economies of all countries;

(d) Necessary arrangements to ensure that mitigation activities actually deliver the expected emission reductions and to promote the implementation of best practices and use of the best available technologies to this end;

(e) Ways and means on how to enhance existing (or create new) instruments and mechanisms based on market approaches that could be applied to the agriculture sector (e.g. programmatic and/or sectoral CDM, sectoral no-lose mechanisms, sectoral agreements, etc.);

(f) Opportunities for technology deployment and enhancement of technology research and development in key areas in the agriculture sector;

(g) Key challenges in measuring, reporting and verifying emission reductions from emission abatement practices in the agriculture sector;

(h) Reasons for, and implications of, the gap between the technical and the economic mitigation potential of the agriculture sector.

38. The issues described in this paper could inform Parties in the upcoming AWG-LCA discussions on the challenges and opportunities for mitigation in the agriculture sector, including the discussions at the workshop on agriculture to be held in March–April 2009.

# II. Introduction

## A. Mandate

39. The AWG-LCA, at its second session, requested the secretariat, subject to the availability of financial resources, to prepare and make available for consideration at its fourth session a technical paper on challenges and opportunities for mitigation in the agriculture sector.[3]

## B. Objectives

40. In response to the request mentioned in paragraph 39 above, this technical paper provides information that aims to contribute to the better understanding of the challenges and the opportunities associated with the implementation of approaches and strategies relating to the mitigation of emissions from the agriculture sector. The paper provides an overview of possible practices (both existing and those that are being developed), addresses the relative potential, methodological and technical challenges and possible barriers for their implementation with the aim of informing the Parties when considering the role of the agriculture sector in mitigating climate change in the context of the Bali Action Plan (decision 1/CP.13).

## C. Approach to the paper

41. The paper covers emissions from enteric fermentation; manure management; agricultural soils; rice cultivation; prescribed burning of savannas; and field burning of agricultural residues. Other activities covered include soil C sequestration in agricultural soils, agroforestry systems and reducing land conversion in the agriculture sector.

42. Chapter II provides background information on GHG emissions from the agriculture sector, trends in emissions and their projected growth. Global mitigation potential and costs, including livestock and manure management, emissions from soils, methane ($CH_4$) emissions from rice cultivation, land-use change, bioenergy from agriculture, sequestration strategies, and energy in agriculture, are addressed in chapter III of this paper. Global mitigation potential and costs are addressed in chapter IV and mitigation practices for livestock and manure management are addressed and provided in chapter V and relevant case studies in chapter VI. Mitigation practices for crops and soils are addressed in chapter VII and relevant case studies are presented in chapter VIII. The mitigation practices presented provide descriptions of existing, emerging and/or future mitigation practices, highlighting opportunities and challenges for each practice, including barriers to implementation, a discussion of the methodological aspects of each practice and the identification of win-win options, best practices and, when applicable, co-benefits and synergies. Chapter IX identifies policies and measures that take into account national circumstances on the basis of challenges and/or barriers, opportunities, co-benefits and possible contribution to sustainable development. Regional circumstances regarding the feasibility and applicability of mitigation practices are considered. Recommendations for future work and issues that may need to be considered further are addressed in Chapter X.

[3] FCCC/AWGLCA/2008/8, paragraph 28 (a).

43. Sources of information presented in this paper include the AR4, national GHG inventories and national communications submitted by Parties to the Convention, as well as other publications, including published reports and papers, that may be of relevance for the work of Parties on the agriculture sector.

# III. Background

## A. General

44. The role of agriculture in the global efforts to address climate change has been recognized in the context of the UNFCCC process. According to Article 2 of the Convention, stabilization of GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system should be achieved within a time frame sufficient […] to ensure that food production is not threatened.

45. Agriculture has also been identified as one of the sectors for which all Parties, taking into account their common but differentiated responsibilities and their specific national and regional development priorities, objectives and circumstances, are:

(a) To promote and cooperate in the development, application and diffusion, including transfer, of technologies, practices and processes that control, reduce or prevent anthropogenic emissions of GHGs (Article 4, paragraph 1 (c), of the Convention); and

(b) To formulate, implement, publish and regularly update national and, where appropriate, regional programmes containing measures to mitigate climate change and measures to facilitate adequate adaptation to climate change (Article 10 of the Kyoto Protocol).

46. Furthermore, Article 2 of the Kyoto Protocol provides for the implementation and/or further elaboration of policies and measures by Parties included in Annex I to the Convention, including the promotion of sustainable forms of agriculture in light of climate change considerations.

47. Agriculture provides the primary source of livelihood for more than one third of the world's total workforce, who produce the food needed to sustain the almost seven billion people living on our planet. In the heavily populated countries of Asia and the Pacific, up to half of the population work in the agriculture sector, while two thirds of the working population in sub-Saharan Africa make their living from agriculture (FAOSTAT, 2008; ILO, 2007).

48. Agricultural lands are lands used for agricultural production and consist of cropland, managed grassland and permanent crops, including agroforestry and bioenergy crops. They occupy about 40–50 per cent of the Earth's land surface (FAOSTAT, 2008) and are expanding. Most of the agricultural lands are used for pasture (about 70 per cent), approximately 27 per cent are arable lands, mainly devoted to annual crops and only a small part (less than 3 per cent) for permanent crops.

49. Croplands comprise arable and tillable land, rice fields and agroforestry systems, where the vegetation structure falls below the thresholds used for the forest land category and is not expected to exceed those thresholds at a later time (Eggleston et al., 2006). All annual and perennial crops as well as temporary fallow land (i.e. land set at rest for one or several years before being cultivated again) are included. Annual crops include cereals, oil seeds, vegetables, root crops and forage crops. Perennial crops include trees and shrubs in combination with herbaceous crops (e.g. agroforestry) or orchards, vineyards and plantations such as cocoa, coffee, tea, oil palm, coconut, rubber trees and bananas, except where these lands meet the criteria for categorization as forest land. Arable land that is normally used for the cultivation of annual crops but is temporarily used for forage crops or grazing as part of an annual crop and pasture rotation (mixed system) is included under cropland (Eggleston et al., 2006).

50. Since 1961 global agricultural production has been steadily increasing at an average annual growth rate of 2.3 per cent, driven by an increasing population, technological change, public policies and economic growth. During the same period, an average of 6 million hectares (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 world where the population is increasing (the world's population grew annually by 1.7 per cent for the period 1961–2006 and reached 6 billion in 1999). However this growth in the production of food and fibre has been at the expense of increased pressure on the environment, has resulted in the depletion of natural resources (Rees, 2003; Tilman et al., 2001) and has not fully addressed the problems of food security and poverty in poor countries.

51. Food production is expected to double in the next 30 years in order to feed the planet's growing human population. According to projections by the Organization for Economic Cooperation and Development (UNFCCC, 2007a), cropping agriculture is expected to grow rapidly in Africa and the Middle East, moderately in most developed countries and in economies that are either emerging or in transition, and is expected to decline in Japan. For livestock populations, high growth rates are expected in Africa, India, South and Southeast Asia and the Middle East, moderate growth rates are expected in most developed countries and in economies that are either emerging or in transition, while livestock numbers are expected to decline in Japan.

52. Such scenarios are driven by the following factors: greater demand for food as a result of the increasing human population, which is projected to be about 7.8 billion people by 2025 stabilizing at about 9 billion people (Lupien and Menza, 2008); an increasing global GDP (from USD 9,253 per capita in 2004 to USD 17,196 per capita in 2030 (UNFCCC, 2007a); 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.

## B. Sources of emissions

53. The GHGs of concern in agriculture are $CO_2$, $CH_4$ and $N_2O$. Other gases (from combustion and soils) are nitrogen oxide ($NO_X$), ammonia ($NH_3$), non-methane volatile organic compounds and carbon monoxide, which are GHG precursors (indirect emissions) in the atmosphere.

54. For the purpose of this paper, the focus will be on $CH_4$ and $N_2O$ emissions from agricultural production and on management practices for C capture and storage in soils. The sections that follow provide brief descriptions of the origins and mechanisms for the release of GHGs from key agricultural activities.

### 1. Enteric fermentation

55. Methanogenic bacteria that exist naturally in ruminal microflora are responsible for the formation of $CH_4$ inside the digestive system of animals. Cattle, buffalo, sheep, goats (i.e. ruminant animals) are the most important sources of enteric $CH_4$ emissions. Non-ruminant animals, which have acetogenic bacteria in their digestive tract, also emit $CH_4$ but at lower rates.

56. Enteric emissions depend on the average daily feed intake and the percentage of food converted to $CH_4$. The average daily feed intake can vary considerably and depends on the species and weight of the animal, the energy it requires and its rate of weight gain. For dairy cows, the rate of milk production is also important. Non-dairy cattle produce about half as much $CH_4$ per head as dairy cows. Other parameters affecting enteric $CH_4$ emissions are genetic characteristics and environmental conditions.

### 2. Manure management

57. The decomposition of manure under anaerobic conditions during storage and treatment produces $CH_4$. These conditions occur most readily when large numbers of animals are managed in a confined area (e.g. dairy farms, beef feedlots, and swine and poultry farms), and where manure is disposed of in liquid-based systems (Eggleston et al., 2006).

58. The main factors affecting $CH_4$ 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 depends 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 $CH_4$ 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 thus less $CH_4$ is produced (Eggleston et al., 2006).

### 3. Soils

59. Agricultural soils emit $CO_2$ and $N_2O$ as a result of management practices. $CO_2$ fluxes between the atmosphere and ecosystems are primarily controlled by uptake through plant photosynthesis and releases via respiration, and the decomposition and combustion of organic matter. Agricultural management activities (e.g. residue management, tillage management, fertilizer management) modify soil C stocks by influencing the C fluxes of the soil system (Bruce et al., 1999; Ogle et al., 2005; Paustian et al., 1997). Depending on the management practice, agriculture could become a source or a sink of C USEPA, 2006a).

60. N additions are commonly used to increase crop yields, including the 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. N additions (in dung and urine) by grazing animals can also stimulate $N_2O$ emissions. Similarly, land-use change enhances $N_2O$ emissions if associated with heightened decomposition in soil organic matter and subsequent N mineralization. Increases in $N_2O$ emissions are usually accompanied by increases in soil emissions of $NO_X$, volatilization of $NH_3$ and leaching of nitrate.[4] These lead to increased indirect emissions of $N_2O$ as they are re-deposited on the soil surface. As they re-enter the N cycle, additional $N_2O$ emissions are created.

### 4. Rice cultivation

61. In flooded conditions, such as wetland environments and paddy rice production, a significant fraction of the decomposing dead organic matter and soil organic matter is returned to the atmosphere as $CH_4$. Although virtually all flooded soils emit $CH_4$, net soil C stocks may increase, decrease or remain constant over time, depending on management and environmental controls on the overall C balance. In well-drained soils, small amounts of $CH_4$ are consumed and oxidized by methanotrophic bacteria. The drainage of flooded lands, in particular peatlands, also releases significant $CO_2$ emissions into the atmosphere as the organic matter in the peat is oxidized.

62. About 90 per cent of the world's harvested area of rice paddies is located in Asia, about 60 per cent of which 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

[4] Emissions of $NO_X$ and $NH_3$ are regulated under the Convention on Long-Range Transboundary Air Pollution.

crop management (Adhya et al., 2000; Chareonsilp et al. 2000; Corton et al., 2000; Setyanto et al. 1997; Wang et al., 2000; and Wassmann et al. 2000).

### 5. Land-use change

63. Emissions from the conversion of natural ecosystems to agriculture (cropland and pasture land) primarily result from C stock losses. All the above-ground biomass from the natural ecosystem is generally lost and replaced by either pasture grasses or seasonal crops. In the case of crops, the land generally spends at least part of the year with little or no above-ground biomass.

64. There are some additional emissions from fossil fuels associated with mechanized land clearing, but these emissions are generally a very small portion of the total emissions. Fire is often used as a land clearing tool and this leads to both $N_2O$ and $CH_4$ emissions. Finally, there are emissions associated with management after land-use change (e.g. $N_2O$ emissions associated with fertilizer use). These emissions represent a small fraction of emissions and most emissions from land-use change are from C stock losses.

## C. Emission levels and trends

65. Agriculture accounts for 5.1–6.2 Gt $CO_2$ eq per year (that is, about 10–12 per cent) of the total global anthropogenic emissions of GHGs (IPCC. 2007b). Between 1990 and 2005, global emissions from agriculture increased by 18 per cent; the average annual growth being about 60 Mt $CO_2$ eq (see figure 1). In 2005 $CH_4$ and $N_2O$ accounted for about 3.3 and 2.8 Gt $CO_2$ eq per year respectively, that is, about 47 per cent of total anthropogenic $CH_4$ and about 58 per cent of total global anthropogenic $N_2O$ emitted in the world. About 74 per cent of agricultural emissions come from developing countries.

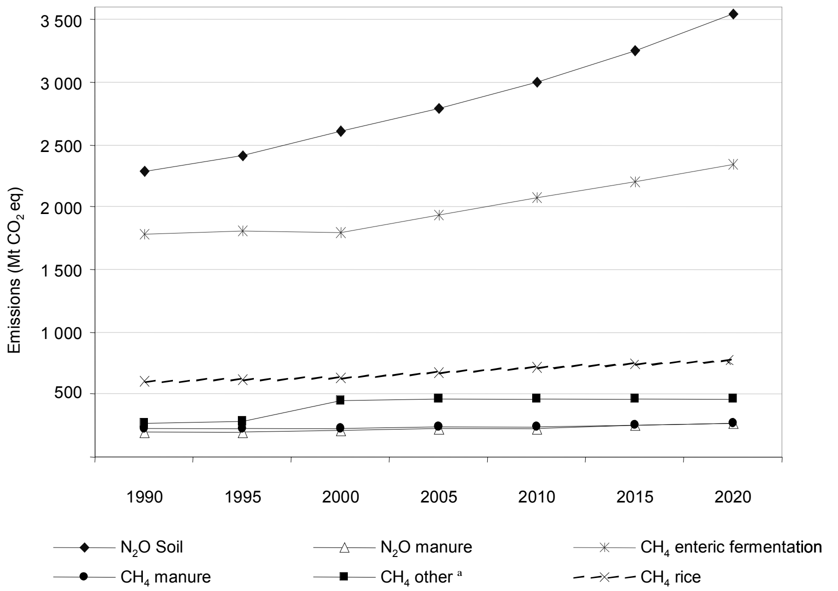
66. Apart from $CH_4$ from biomass burning, the highest increase in emissions in 2005 was $N_2O$ from soil (up 22 per cent on 1990 levels). $N_2O$ emissions from manure management and $CH_4$ emissions from rice cultivation both increased by 12 per cent.

67. In the absence of mitigation measures, emissions from agriculture are projected to continue to grow. According to the IPCC (IPCC. 2007b), agricultural $N_2O$ emissions are projected to increase by 35–60 per cent, while $CH_4$ emissions are expected to increase by 60 per cent. Future trends for all main sources of global non-$CO_2$ GHG emissions are shown in figure 1.

68. Between 1990 and 2005 agricultural emissions in developing countries increased by 32 per cent, resulting in these countries being responsible for about 75 per cent of total agricultural emissions in 2005. During the same period, agricultural emissions in developed countries decreased by about 12 per cent. Emissions of non-$CO_2$ GHGs were highest in South and Southeast Asia and the Latin America and Caribbean regions (see figure 2). In the absence of mitigation measures, emissions in these regions are expected to grow rapidly. Emissions in sub-Saharan Africa are also expected to grow rapidly. Emissions from Central West Asia and North Africa (CWANA), "other developed countries" and Eastern Europe (figure 2) are relatively low and are expected to grow at a moderate pace. Emissions are expected to decline in Western Europe.

69. Although the dominant sources of non-$CO_2$ GHG emissions are $N_2O$ emissions from soils and $CH_4$ emissions from enteric fermentation in all regions, each region has other additional large sources of emissions: in particular, $CH_4$ emissions from rice cultivation in South and Southeast Asia; $CH_4$ emissions in sub-Saharan Africa and Latin America and the Caribbean (mainly due to savannah burning in tropical areas); and $CH_4$ emissions from manure management in Western Europe. Other sources generally represent less than 10 per cent of regional emissions.

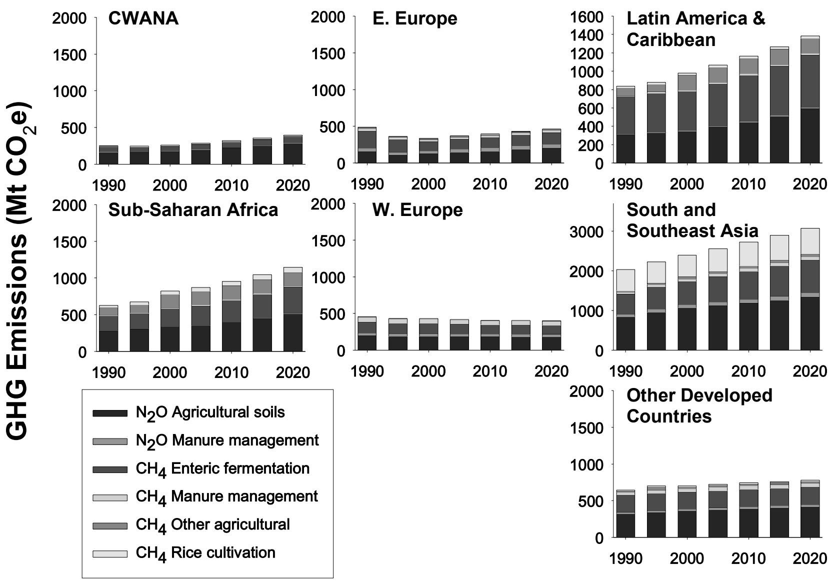
**Figure 1. Trends for global non-carbon dioxide greenhouse gas emissions, by source, 1990–2020**




*Source:* United States Environmental Protection Agency. 2006. *Global Anthropogenic Non-$CO_2$ Greenhouse Gas Emissions: 1990–2020*. Washington DC: USEPA.

[a] "$CH_4$ other" refers to biomass burning.

**Figure 2. Regional non-carbon dioxide greenhouse gas emissions from agriculture, actual and projected, 1990–2020**



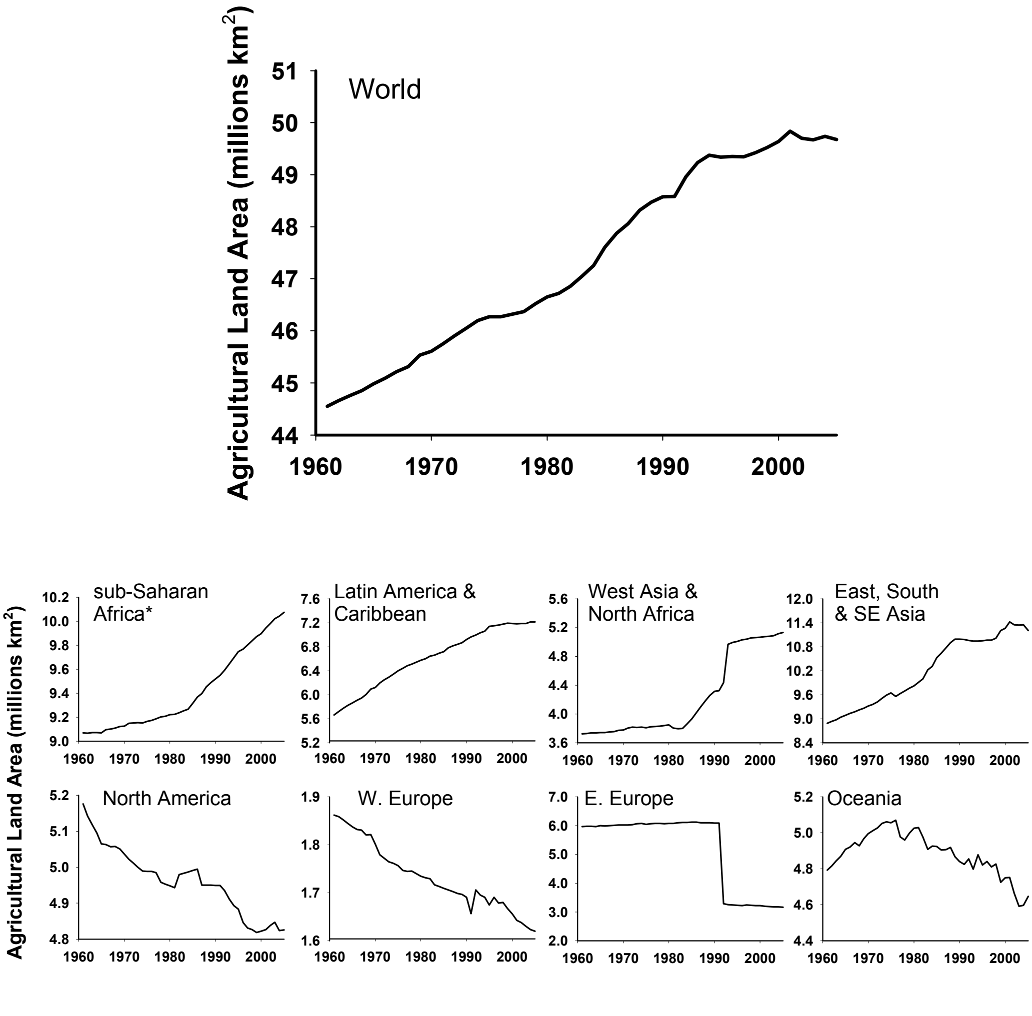

*Source*: United States Environmental Protection Agency. 2006. *Global Mitigation of Non-$CO_2$ Greenhouse Gases*. Washington DC: USEPA.

*Abbreviations*: CWANA = Central West Asia and North Africa, E. Europe = Eastern Europe, W. Europe = Western Europe.

70. GHG emissions from land-use change in tropical countries (about 7.6 Gt $CO_2$ eq) exceed emissions from all other agricultural sources combined and continue to grow as areas of cropland and pasture land increase. In 2005 agricultural lands occupied 49.7 million $km^2$ (FAOSTAT, 2008), having increased by about 5 million $km^2$ since the early 1960s (see figure 3). Pasture land accounted for 65 per cent of the increase and arable and permanent croplands accounted for the remaining 35 per cent.

71. Since 1965 land under row crops and permanent crops have increased in sub-Saharan Africa (37 per cent), West Asia and North Africa (28 per cent), East, South and Southeast Asia (23 per cent), Latin America and the Caribbean (48 per cent) and Oceania (32 per cent). Recent trends suggest that land area for cropping is levelling off in Latin America. Likewise, the area under meadow and pasture is increasing in West Asia and North Africa (40 per cent), East, South and Southeast Asia (24 per cent), Latin America and the Caribbean (48 per cent) and Oceania (32 per cent). Short-term trends suggest that growth of pasture area may be levelling off in all regions, with the exception of sub-Saharan Africa (FAOSTAT, 2008).

**Figure 3. Global and regional land-use change to agricultural land (cropland and pasture land)**



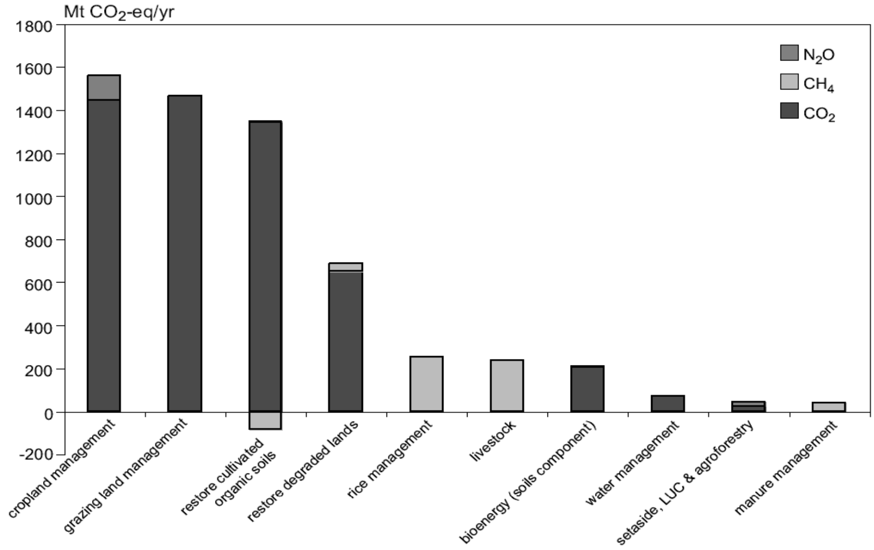

*Source:* Food and Agriculture Organization of the United Nations. FAOSTAT database <http://faostat.fao.org>.
*Abbreviations*: SE Asia = South East Asia, W. Europe = Western Europe, E. Europe = Eastern Europe.
Notes: (1) Ethiopia was not included in the chart for Africa as there were significant reporting discrepancies following the separation with Eritrea.
(2) Note different Y axis scales for each chart.

# IV. Global mitigation potential and costs

72. Several mitigation options exist for reducing GHG emissions from agriculture, including: improving livestock and manure management; improving cropland and grassland management (e.g. improving agronomic practices, including nutrient use, tillage and residue management); restoring drained organic soils for crop production; restoring 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); agroforestry; sequestration of C in agroecosystems; and producing fossil fuel substitutes. For many of these mitigation opportunities, existing technologies can be implemented immediately, provided that economic, financial, social, cultural and/or educational barriers are overcome.

73. According to the IPCC (IPCC. 2007b), the technical mitigation potential[5] of agriculture (considering all gases and sources) in 2030 is estimated to be between 4.5 Gt $CO_2$ eq per year and 6 Gt $CO_2$ eq per year. About 89 per cent of this potential can be achieved by soil C sequestration through cropland management, grazing land management, restoration of organic soils and degraded lands, bioenergy and water management (see figure 4). Mitigation of $CH_4$ can provide an additional 9 per cent through improvements in rice management and livestock and manure management. The remaining 2 per cent can be achieved from mitigation of $N_2O$ emissions from soils, mainly through crop management.

**Figure 4. Global technical mitigation potential by 2030 of each agricultural management practice showing the impacts of each practice on each greenhouse gas**




*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).
*Abbreviations*: LUC= Land-use change
*Note*: The analysis is based on the B2 scenario of the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change, though the pattern is similar for all the Special Report on Emissions Scenarios in the AR4.

[5] Technical mitigation 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 been demonstrated already. No explicit reference to costs is made, but adopting 'practical constraints' may take into account implicit economic considerations (IPCC AR4).

74. The economic potential[6] of all agricultural management practices in 2030 is considerably lower than the technical potential, estimated to be 1.5–1.6 Gt$CO_2$ eq per year (at a C price of USD 20 per t $CO_2$ eq); 2.5–2.7 Gt $CO_2$ eq per year (at a C price of USD 50 per t $CO_2$ eq); and 4–4.3 Gt $CO_2$ eq per year (at a C price of USD 100 per t $CO_2$ eq). About 30 per cent of this potential can be achieved in developed countries and 70 per cent in developing countries (IPCC. 2007b).

75. 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 (IPCC. 2007b). Abatement costs, however, are significant compared to current and projected rates of global investment in agriculture. As shown in table 1, the investment needed by 2020 (at a C price of USD 30 t $CO_2$ eq) is of the order of USD 17 billion.

**Table 1. Estimates of the reductions in emissions from non-carbon dioxide and soil carbon greenhouse gases and the investment needed to achieve these reductions between 2000 and 2020**

| | **Year** | | | | | |
|---|---|---|---|---|---|---|
| | **2000** | | **2010** | | **2020** | |
| **Sub-sector** | **Reductions (Mt $CO_2$ eq)** | **Cost (USD billion)** | **Reductions (Mt $CO_2$ eq)** | **Cost (USD billion)** | **Reductions (Mt $CO_2$ eq)** | **Cost (USD billion)** |
| Cropland | 172 | 7.74 | 183 | 5.48 | 168 | 5.04 |
| Rice | 200 | 6.00 | 226 | 6.79 | 238 | 7.14 |
| Livestock | 131 | 3.93 | 143 | 4.28 | 158 | 4.73 |
| **Total** | **503** | **17.67** | **552** | **16.55** | **564** | **16.91** |

*Source*: Analysis based on United States Environmental Protection Agency abatement curves. United States Environmental Protection Agency. 2006. *Global Mitigation of Non-$CO_2$ Greenhouse Gases*. Washington DC: USEPA.
*Notes:* (1) At a carbon price of USD 30 per t $CO_2$ eq
(2) costs are given in 2000 USD.

76. Reductions in investments by developing countries and reductions in official development assistance for agriculture over the past three decades have led to land degradation and the spread of subsistence agriculture systems. This, in turn, has led to C losses from natural ecosystems. Investments aimed at sequestration and the intensification of agricultural systems can reverse this trend (Verchot et al., 2007).

77. Although many agricultural practices are economically feasible, they are not implemented due to a number of barriers (e.g. lack of knowledge, lack of access to technology). Investment targeted at overcoming these barriers is estimated as much less than the total cost of implementation. One analysis (Verchot, 2007) suggests that the cost associated with overcoming some of these barriers could be less than USD 4.5 per t $CO_2$ eq.

### A. Livestock and manure management

78. Emissions from livestock and manure management depend largely on the practices that are employed. Although differences between regions and countries exist in terms of how animal herds are managed at the farm level, some similarities can be found at the species level. In particular:

[6] 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, that is, non-market costs and benefits such as environmental co-benefits (IPCC AR4).

(a) Dairy cows are mainly managed under confinement during the lactation period, receiving a highly enriched diet, while beef cattle are predominantly managed under grazing conditions. Regional differences are caused by pastures and the productivity of the animals;

(b) Sheep and goats are kept as grazing animals. In exceptional cases, they are kept confined due to forage quality or animal genetics;

(c) Horses are mainly kept as grazing animals, except under special circumstances (e.g. racing horses);

(d) Swine and poultry are typically raised under confinement and are mainly fed with grains and concentrates;

(e) Buffaloes are mainly managed under grazing conditions.

79. Several practices, ranging from pasture management to dietary additives, are known to reduce enteric $CH_4$ emissions. The main efforts to improve the diet of animals have been focused on optimizing feeding practices and pasture management. Farmers can apply different strategies for feeding their animals, ranging from predominantly grazing conditions (extensive systems that are strongly influenced by environmental conditions) to predominantly confined systems (intensive systems, on the whole not affected by environmental conditions). Confined systems are better suited for controlling the diet of animals and the daily administration of additives. As a result of changes in diet, manure composition may have a lower N content, which leads to lower $N_2O$ emissions.

80. $N_2O$ emissions from manure management are a function of the amount of manure produced, the type of manure management and the diet given to the animals. Usually a combination of waste treatment systems (e.g. anaerobic lagoons, daily spread, liquid systems, dry lot, solid storage, digesters) is used for all animal species. For confined swine, liquid treatment (including anaerobic lagoons) is the dominant system. For confined poultry, the main waste treatments used are solid systems, although in some cases liquid systems are also used. For grazing animals (such as sheep and goats), there are some specific cases of confinement that are linked to daily spread, dry lot and liquid treatment systems.

### B. Emissions from soils

81. As mentioned above, soils represent one of the most important sources of non-$CO_2$ GHG emissions from agriculture. One mitigation practice is the reduction of $N_2O$ emissions from excess fertilizer applications, whilst maintaining high yield rates for crops. Using the DayCent model for maize, soybean and wheat, estimates of the technical potential for the reduction of global $N_2O$ emissions have been produced (USEPA, 2006b) for the following agronomic and nutrient management practices:

(a) Split fertilization: Application of the same amount of fertilizer as in the baseline, but divided into three smaller increments. Only the $N_2O$ implications of this practice were considered in this analysis, the emissions from the additional energy required to apply the fertilizer were not taken into account;

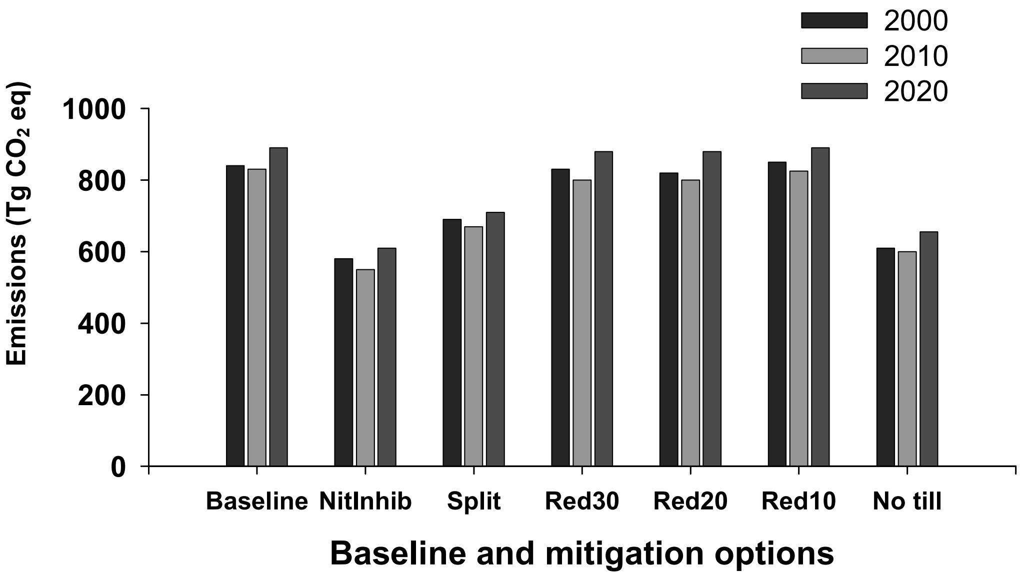
(b) Simple fertilizer reduction of 10, 20 and 30 per cent with a single application;

(c) Application of nitrification inhibitors, which reduce the conversion of ammonium to nitrite;

(d) Reduced tillage to maintain higher levels of soil organic matter. This practice maintains the soil C, but tends to increase $N_2O$ emissions.

82. The DayCent modelling exercise was conducted at the global scale, and thus this is how the results should be interpreted. Globally, reduced N fertilization had little impact on emissions, while the use of reduced tillage and nitrification inhibitors had the greatest impact (see figure 5). Furthermore, reducing N inputs reduced soil C stocks, thus offsetting the small reductions in $N_2O$ emissions. Greater reductions were achieved by using nitrification inhibitors such as nitrapyrin, diycaydiamide, or DMPP (3,4-dimethylpyrazole phosphate). Reduced tillage and the splitting of fertilizer application to match plant demand better also reduced emissions greatly.

**Figure 5. Global net greenhouse gas emissions from croplands (nitrous oxide and soil carbon)**




*Source*: Adapted from United States Environmental Protection Agency. 2006. *Global Mitigation of Non-$CO_2$ Greenhouse Gases*. Washington DC: USEPA.
*Abbreviations*: NitInhib = nitrification inhibitors, Split = split fertilization application, Red30 = fertilizer reduction of 30% with simple application, Red20 = fertilizer reduction of 20% with simple application, Red10 = fertilizer reduction of 10% with simple application, No till = no tillage.
*Note*: Estimations using DayCent model under baseline and mitigation scenarios.

83. In addition, the USEPA (2006b) generated regional abatement cost curves and a globally aggregated abatement cost curve. The curves assume a constant cultivated area, which is reasonable for analyses over short time frames. These curves were used to generate the summary of potential net reductions at different C prices for croplands (see table 2). These reductions are for both $N_2O$ emissions and soil C.

84. Globally, approximately 15 per cent of the net emissions from croplands can be mitigated at a net benefit or at no cost (less than USD 0 per t $CO_2$ eq). Approximately 20–23 per cent of the net emissions (about 190 Mt $CO_2$ eq) can be mitigated for less than USD 30 per t $CO_2$ eq. For higher reduction rates, costs rise rapidly.

**Table 2. Potential reductions in net emissions (nitrous oxide and soil carbon) from croplands for selected countries and regions, at two different emissions reductions costs**
*(million tonnes of carbon dioxide equivalent)*

| Country, region or grouping | Reductions in 2010: USD 0 per t $CO_2$ eq | Reductions in 2010: USD 30 per t $CO_2$ eq | Reductions in 2020: USD 0 per t $CO_2$ eq | Reductions in 2020: USD 30 per t $CO_2$ eq |
|---|---|---|---|---|
| Africa | 3.6 | 4.4 | 3.8 | 4.9 |
| Annex I Parties | 99.7 | 143.7 | 102.1 | 126.1 |
| Australia and New Zealand | 3.6 | 4.2 | 3.7 | 4.4 |
| Brazil | 1.6 | 4.0 | 1.4 | 3.7 |
| China | 6.2 | 6.5 | 6.0 | 7.6 |
| Eastern Europe | 5.7 | 8.2 | | 8.5 |
| EU-15 | 11.1 | 12.1 | 10.9 | 11.5 |
| India | 4.3 | 7.9 | 4.2 | 8.4 |
| Japan | – | – | – | – |
| Mexico | 1.7 | 3.7 | 2.9 | 6.5 |
| Non-OECD Annex I Parties | 34.8 | 58.8 | 34.7 | 39.3 |
| OECD | 60.8 | 80.4 | 63.4 | 82.1 |
| Russian Federation | 34.8 | 58.8 | 34.7 | 39.3 |
| South and Southeast Asia | 2.1 | 2.5 | 2.3 | 3.1 |
| United States of America | 38.8 | 51.0 | 40.6 | 53.0 |
| **Global total** | **127.8** | **182.6** | **130.4** | **167.9** |

*Source*: Adapted from United States Environmental Protection Agency. 2006. *Global Mitigation of Non-$CO_2$ Greenhouse Gases*. Washington DC: USEPA.
*Abbreviations*: EU-15 = Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden and the United Kingdom, OECD = Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom and United States.
*Note*: Costs are given in 2000 United States dollars.

### C. Methane emissions from rice cultivation

85. Permanent flooding favours the formation of large amounts of $CH_4$, whereas even short periods of soil aeration significantly reduce emission rates. Ample and evenly distributed rainfall can create soil conditions comparable to irrigated rice cultivation in some rain-fed systems (Khalil and Shearer., 2006). Persistent flooding throughout the growing season, which is a relatively common occurrence during the wet season in large areas of Southeast Asia, also leads to high emissions.

86. Another factor determining the level of emission rates is the quantity and quality of organic inputs. Traditional agriculture uses relatively large amounts of manure, which leads to high emission rates. The decline in this practice over the last few decades has subsequently led to major reductions in $CH_4$ emissions from rice fields. Mixing crop residues (i.e. straw, stubble and roots) with soil in rice fields generally stimulates emissions, but the incremental effect depends upon when the residues are applied.

87. Changes in water management, such as mid-season drainage, can reduce $CH_4$ emissions (Corton et al, 2000; Wang et al. 2000; and Wassmann et al. 2000). However, there are trade-offs, as drainage usually increases $N_2O$ emissions, particularly in heavily-fertilized systems. Unfortunately, these trade-offs are poorly quantified (Verchot et al., 2004). Practices that alter organic matter management and decrease low-quality organic matter inputs to soils during periods when they are likely to increase $CH_4$ production can also reduce $CH_4$ emissions.

88. Using the regional abatement cost curves from USEPA (2006b), a summary of potential net reductions at different C prices for croplands was generated (see table 3). These reductions are for both non-$CO_2$ GHG emissions and soil C in rice systems.

**Table 3. Potential reductions of emissions from rice cultivation for selected countries, regions and groupings at two different carbon prices**
*(million tonnes of carbon dioxide equivalent)*

| | 2010 | | 2020 | |
|---|---|---|---|---|
| **Country/Region/Grouping** | **At USD 0 per t $CO_2$ eq** | **At USD 30 per t $CO_2$ eq** | **At USD 0 per t $CO_2$ eq** | **At USD 30 per t $CO_2$ eq** |
| Annex I | 0.4 | 6.7 | 0.4 | 6.6 |
| China | 47.6 | 90.3 | 39.6 | 81.5 |
| India | – | 27.4 | – | 31.6 |
| Japan | 0.4 | 6.7 | 0.4 | 6.6 |
| OECD | 1.7 | 10.7 | 1.9 | 10.8 |
| South and Southeast Asia | 60.6 | 97.9 | 71.9 | 113.5 |
| **Global total** | **109.0** | **226.3** | **113.6** | **237.9** |

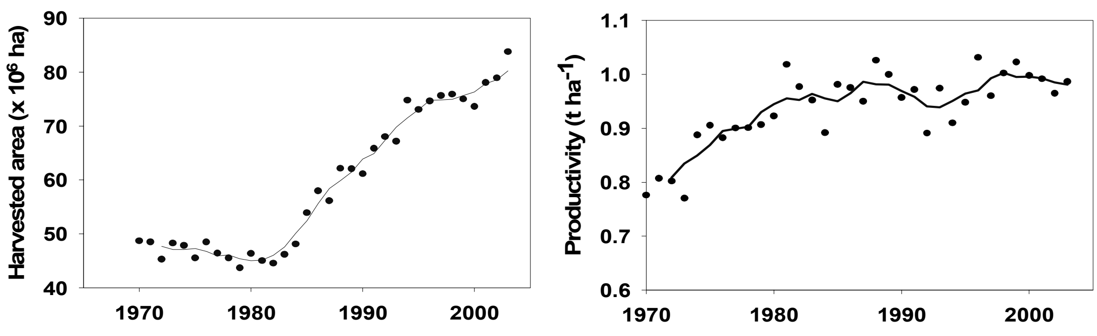
*Source*: Table adapted from United States Environmental Protection Agency. 2006. *Global Mitigation of Non-$CO_2$ Greenhouse Gases*. Washington DC: USEPA.
*Abbreviations*: OECD = Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom and United States.
*Note*: Costs are given in 2000 United States dollars.

89. Globally, in 2000 approximately 3 per cent of net emissions from rice cultivation could have been mitigated at a net benefit or at no cost (less than USD 0 per t $CO_2$ eq). At a price of USD 30 per t $CO_2$ eq, 13 per cent could have been mitigated in 2000, but for higher emission reductions, the costs rise sharply. Because of the expected increase in rice production, in 2010 11 per cent of the emissions could be reduced at a net benefit or no cost. At a C price of USD 30 per t $CO_2$ eq, the mitigation potential in 2010 would increase to 22 per cent.

## D. Land-use change

90. An effective way to reduce emissions associated with the conversion of land to agriculture is by intensifying agriculture, that is, producing more crops on land already in production. Another option is to increase C stocks through regenerating forests and protecting them from conversion to other uses. However, land conversion rates can be slowed in cases where the need for increased agricultural productivity is driving land-use change (see for example figure 6 which shows the relationship between harvested area and productivity in sub-Saharan Africa).

**Figure 6. Harvested area (left panel) and productivity (right panel) for all cereals in sub-Saharan Africa, 1970-2000**




*Source*: Food and Agriculture Organization of the United Nations. FAOSTAT database <http://faostat.fao.org>.

### E. Bioenergy from agriculture

91. Bioenergy (which is used to replace fossil fuels) is obtained from agricultural feedstocks and dedicated energy crops. Its energy production 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 per year, while energy supply available from agricultural biomass is projected to be in the range of 100 EJ per year up to above 400 EJ per year by 2050. The technical potential for energy cropping on land currently used for agriculture, with projected technological progress in agriculture and livestock, could deliver over 800 EJ per year without jeopardizing the world's food supply (Smeets et al. 2007).

92. There are many promising technologies for converting biomass into energy including: direct combustion of biomass for the production of heat and power; gasification of biomass to produce a synthetic gas (syngas) that can be combusted in high-efficiency combined heat and power systems; biological conversion of animal waste to $CH_4$ as a source of heat, power, and fuels; biological release and converting sugars in biomass to produce ethanol; thermochemical conversion of biomass-derived syngas to produce transportation fuels; and chemical conversion of natural oils to fuels, including biodiesel (Paustian et al., 2004). Second generation biofuels (for example lignocellulosics, dimethylfuran) are currently being developed.[7] Given that they are still at the experimental stage, no projections can be made about their future availability.

93. The contribution of biofuels to the reduction of GHG emissions depends on: whether they can be produced on local farms at competitive prices; whether the energy derived from these crops will be cost-competitive with fossil energy sources; and whether the ecological and economic benefits of biofuels will be factored into the pricing and/or evaluation equation (Paustian et al. 2004).

### F. Sequestration strategies

94. C sequestration in agroecosystems holds great promise as a tool for climate change mitigation (Albrecht and Kandji, 2003; Lal, 2004a), in particular because they also offer opportunities for synergy with development objectives. Increased C stocks can be achieved through reduced respiration losses associated with changes in tillage practices and through changes in land use. Agricultural lands also remove small amounts of $CH_4$ from the atmosphere by oxidation, although they remove less than forests (Tate et al., 2006; Smith and Conen, 2004; Verchot et al., 2000).

95. Land management in the agriculture sector offers significant opportunities for C sequestration through improved grassland management, cropland management and agroforestry. For improved grassland management, high rates of sequestration can be achieved by introducing more productive grass species and legumes. Legumes may increase $N_2O$ emissions, offsetting at least part of the additional sequestration. Improved nutrient management and irrigation can also increase the productivity of grazing animals and can sequester more C but can also increase $N_2O$ emissions.

96. The expanding role of agroforestry offers the potential for synergies between mitigation programmes and adaptation to climate change (Verchot et al., 2007). In many instances, improved agroforestry systems can reduce the vulnerability of small-scale farmers to inter-annual climate variability and help them adapt to changing conditions.

97. Grazing land management, despite the low C density of grazing land, has a high potential for C sequestration because of the large amount of land that can be converted (3.4 billion ha). High rates of

[7] For further reference, see: Sims REH, Hastings A, Schlamadinger B, Taylor G and Smith P. 2006. Energy crops: current status and future prospects. Global Change Biology 12: pp. 2054–2076. doi:10.1111/j.1365-2486.2006.01163.x.

sequestration can be achieved by introducing more improved grass species and legumes. Improved nutrient management and irrigation can also increase productivity and sequester C. However, for soil carbon to increase, grazing needs to be carefully managed, as overgrazing could lead to a decline in soil C.

98. Cropland management (which includes residue management, tillage intensity, fertilizer management, crop choice and rotation, as well as irrigation) modifies soil C stocks (IPCC. 2007b). The nature of the modification depends on how each practice influences C input and output from the soil (Bruce et al., 1999; Paustian et al., 1997; and Ogle et al., 2005). Organic soils are particularly vulnerable to modification, as the drainage and cultivation of organic soils reduces soil C stocks (Armentano and Menges, 1986). In addition, potential negative impacts would need to be considered, given that the introduction of some grass species and the application of N fertilizer may also lead to higher $N_2O$ emissions and changes to legume plants in the pasture mix (IPCC. 2007b).

99. At the global level, other land-use options, such as the restoration of degraded land and wetlands, have a relatively low potential to contribute to mitigation of emissions, particularly because of low availability of land and slow C accumulation rates. However this potential (and its co-benefits) may be significant at the local level.

100. It should be noted that many grassland species have developed adaptation mechanisms, resulting in the vegetation and soil C being relatively resistant to moderate destruction from grazing and fire (Milchunas and Lauenroth, 1993). For many types of grasslands, fire is a key factor in preventing the invasion of woody species that can significantly affect the capacity of the ecosystems to store C (Jackson et al., 2002).

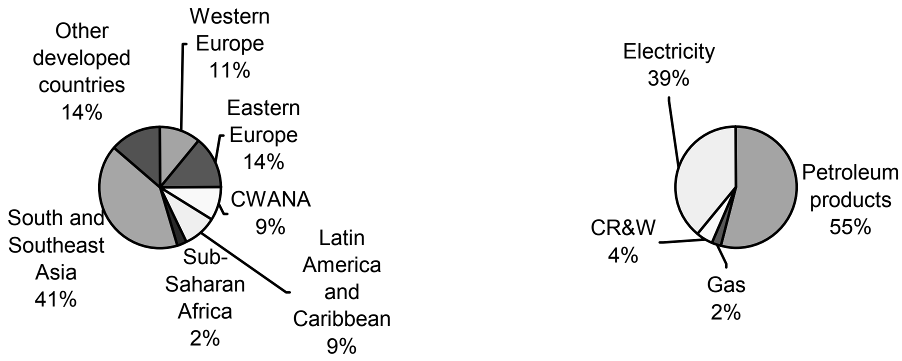
### G. Energy in agriculture

101. Mitigation of energy-related emissions in agriculture is addressed within the context of the energy sector and not as part of mitigation options for agriculture. The energy-related discussion in agriculture usually refers to biofuels (however, their mitigation potential is discussed under the broad energy sector) and the possibility of agriculture providing feedstock from waste products to generate energy in order to offset fossil fuel-generated energy.

102. Using data from the International Energy Agency (fuel consumption data and emissions factors (IEA 2006)), it is possible to disaggregate emissions by region and by main fuel type (see figure 7). Energy-related emissions from agriculture are a relatively small source of emissions, accounting for about 11 per cent of the total emissions from agriculture. In most regions, petroleum products are the major source of energy for agriculture, while electricity is a major contributor in South and Southeast Asia. Developed countries accounted for almost 40 per cent of the total emissions.

103. As a result of the increased mechanization of agriculture, fossil fuel emissions are expected to increase. The recycling of agricultural waste products and the increased use of renewable energy sources (such as biodiesel and ethanol) offer opportunities to reduce fossil fuel emissions. In South and Southeast Asia, where energy-related emissions are highest, biodiesel and electricity generation from renewable energy sources offer meaningful mitigation opportunities.

**Figure 7. Energy-related agricultural greenhouse gas emissions in 2000, by region and by main fuel type**




*Source*: International Energy Agency (IEA). 2006. *$C_2$ Emissions from Fuel Combustion 1971–2004–2006 Editions*. Paris: IEA.
*Abbreviations*: CWANA = Central West Asia and North Africa. CR&W combustible, renewable and waste.

# V. Mitigation practices for livestock and manure management

## A. Current potential mitigation practices

104. Some mitigation practices for livestock and manure management target reductions of GHG emissions directly, while others aim to improve animal productivity or manure practices and also result in reductions of GHG emissions as a co-benefit. Given the strong linkages between the various components of agricultural systems, mitigation practices that are based on changes in how agricultural systems are managed are likely to have an impact on more than one GHG and on other environmental aspects.

105. The sections that follow provide information on mitigation practices related to: the reduction of enteric $CH_4$ emissions by improving animal performance; the reduction of $CH_4$ emissions by improving feeding practices; the reduction of $CH_4$ emissions from manure; the reduction of $N_2O$ emissions from manure; and the reduction of non-$CO_2$ emissions from grazed pastures. Summary information for all of these options is provided in table 29 in the annex to this paper.

106. In addition to the practices presented in the sections that follow, reducing the number of animals also has the potential to reduce emissions. This is not a technical mitigation practice in itself, but it is the result of policies that aim to reduce animal populations in a given country or the result of reducing grazing intensity, which leads to a reduction in the number of livestock per unit of area. However, this practice is not a viable option for livestock farmers (NZ-MAF, 2008) unless it is a national development goal and an enforcement by environmental policies. Furthermore, in the absence of measures that would increase animal productivity, reducing numbers in animal populations in one country or region runs the risk of displacing emissions to other countries or regions, given the need to satisfy the global increasing demand for meat and dairy products. For the purpose of this paper, this particular practice is not considered further.

### 1. Manure management practices

107. **Mitigation potential**: manure accumulation in intensive animal production systems tends to decompose under anaerobic conditions and results in a fermentative digestion process with the production of $CH_4$. The composition of manure can also influence the amounts of $N_2O$ released from manure management practices.

108. Up to 90 per cent of the $CH_4$ emitted by anaerobic manure management systems can be captured and combusted. In the case of composting, 10–35 per cent of the $CH_4$ emitted can be reduced. The mitigation potential for manure management application practices according to the IPCC (IPCC. 2007b) is provided in table 4 below:

**Table 4. Mitigation potential of manure management practices**

| Climate zone | $CO_2$ ($t\ CO_2\ ha^{-1}\ yr^{-1}$) | $CH_4$ ($t\ CO_2\ eq\ ha^{-1}\ yr^{-1}$) | $N_2O$ ($t\ CO_2\ eq\ ha^{-1}\ yr^{-1}$) |
|---|---|---|---|
| Cool-dry | 1.34 (–3.19 to 6.27) | 0.02 (0.01 to 0.02) | 0.00 (–0.17 to 1.30) |
| Cool-moist | 2.79 (–0.62 to 6.20) | 0.00 | 0.00 (–0.17 to 1.30) |
| Warm-dry | 1.54 (–3.19 to 6.27) | 0.00 | 0.00 (–0.17 to 1.30) |
| Warm-moist | 2.79 (–0.62 to 6.20) | 0.00 | 0.00 (–0.17 to 1.30) |

*Source*: IPCC. 2007b. *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmetal Panel on Climate Change* (Metz M, Davidson OR, Bosch PR, Dave R, Mayer LA (eds.), Cambridge University Press, Cambridge, United Kingdom and New York, New York, United States).
*Note*: Values in parentheses correspond to low and high mitigation potential. Positive values represent carbon dioxide uptake which increases the soil carbon stock, or a reduction in emissions of nitrous oxide.

109. Reductions in $N_2O$ emissions due to improved manure application to soils (using optimum N dosage and optimum manure application) may vary from 2 to 50 per cent. Such a wide range is not surprising when dealing with N, which is an element that is highly sensitive to surrounding environmental conditions. Reductions in $N_2O$ emissions as a result of improved effluent management can reach up to 15 per cent. Full accounting of N content in manure has to be performed in order to avoid supplying too much nitrogen when applying synthetic fertilizer.

*Reductions in methane emissions*

110. **How to achieve**: the most promising mitigation practices are: enhancing $CH_4$ production in closed environments (biodigestors, covered manure piles and lagoons) and then burning it or collecting it and using it as biogas; applying aerobic treatments of manure (composting, co-composting, aerobic animal waste treatment systems, the application of manure to soil under aerobic conditions (Hao et al., 2008); cooling manure to below the temperature level at which $CH_4$ is formed (about 10 ºC) (Hao et al., 2008); and mechanically separating solids from slurry and then handling the manure in solid form.

111. **Methodologies used to estimate emissions**: tier 1, tier 2 or tier 3 methods[8] can be applied to estimate reductions in $CH_4$ emissions from manure when implementing practices related to the promotion of aerobic conditions or to the use of $CH_4$ as a biogas. For the latter, increased $N_2O$ emissions as a result of the increased concentration of $NH_3$ in biodigesters has to be taken into account.

112. **Challenges**: although these mitigation practices can be implemented using existing technology, there is a lack of incentives (including financial incentives) for the broad implementation of these mitigation practices by farmers and producers.

[8] In this paper, tier 1, tier 2 and tier 3 methods refer to the IPCC tiers (see IPCC 2006 Guidelines for National Greenhouse Gas Inventories), unless otherwise specified.

113. **Opportunities**: these mitigation practices are applicable to all agricultural waste management systems, especially those related to swine production.

114. **Co-benefits and the contribution to sustainable development**: more environmentally sound management of intensive animal production systems would result in fewer odours and less environmental pollution due to the release of residues into the air. For some activities, C credits can be issued under a CDM project. Certificates for 'clean production' or 'environmentally friendly production' could be issued to farmers by national or regional environmental authorities, thus allowing them to improve their market position in national or international markets.

*Reductions in nitrous oxide emissions*

115. **How to achieve** reductions in $N_2O$ emissions: The main mitigation practices are: reducing N content in manure (due to changes in the diets of animals); covering manure piles to retain N in the manure (Hao et al., 2008); optimizing the application of manure to soils (matching with crop demands or following national regulations), time (when plants are absorbing), and avoiding wet soils (during the rainy season) (de Klein and Eckard, 2008); applying nitrification inhibitors to soils or manure piles in order to improve the nitrification process; increasing the hippuric acid content of urine as a result of diet changes (de Klein and Eckard, 2008; Kool et al., 2006); taking advantage of the inhibitory effect of benzoic acid on microbial activity in general and in particular denitrification (Her and Huang 1995; Fenner et al. 2005).

116. **Methodologies used to estimate emissions**: tier 3 methods are needed to fully account for $N_2O$ emission reductions from effluent management and land applications, although tier 2 methods with specific emission factors, if available, can be also applied. In the case of amount of N applied to soils, tier 1 methods can account for $N_2O$ emission reductions.

117. **Challenges**: farms, especially in developed countries and highly populated areas, may not have enough agricultural land for the application of all the manure that could be produced. Professional assistance and incentive programmes are needed to reach out to farmers and improve farming practices.

118. **Opportunities**: the land application of manure is universally considered to be an environmentally friendly practice and national environmental policies are promoting this practice as compatible with clean production systems. However, careful management of sites and farming may be required in order to avoid excessive application and consequent surface and ground water pollution.

119. **Co-benefits and the contribution to sustainable development**: the main co-benefits of this set of practices, provided that they are applied properly, are the reduction of groundwater pollution, the improvement of grassland productivity, the reduction of soil erosion and a reduction in the use of mineral N fertilizers; as a whole, there would be increased profitability. Through the development of voluntary agreements, certificates for 'clean production' or 'environmentally friendly production' could be issued to farmers, allowing them to improve their market position in national or international markets.

2. Feeding practices

120. **Mitigation potential**: For $CH_4$ emissions from enteric fermentation: 1–22 per cent for dairy cows; 1–14 per cent for beef cattle; 1–6 per cent for sheep; 4–10 per cent for dairy buffalo and 2–5 per cent for non-dairy buffalo (IPCC. 2007b).

121. **How to achieve**: the main goal of feeding practices is to provide animals with an enriched diet in order to lower their enteric $CH_4$ emissions per output or input unit. However, this may not reduce the absolute amount of $CH_4$ emissions per animal. There are several variables that farmers would have to manage, including: grain supplementation (which is costly, has associated GHG emissions in their production and is mainly only an option for confined animals); use of higher quality forages (in terms of

nutritional values); use of forage from plants containing some natural methanogenic depressors, such as condensed tannins; use of mineral supplements to overcome any possible nutrient deficiencies; and improvement of the conditions where drinking water is provided, to avoid parasitic diseases that would reduce animal yields (DEFRA, 2007; de Klein and Eckard, 2008; and IPCC. 2007b).

122. **Methodologies used to estimate emissions**: changes in enteric $CH_4$ emission rates can be estimated by using tier 2 methods. There are significant difficulties in measuring $CH_4$ emissions from grazing animals. To fully account for the net benefit of feeding practices, changes in GHG emissions in order to increase grain or forage production must be taken into consideration.

123. **Challenges**: the results of feeding practices cannot be guaranteed and any implementation of a practice has to be assessed by field measurements. The mitigation potential will vary depending on whether farmers are dealing with confined animals (using intensive farming systems, which are almost unaffected by environmental conditions and make it easier to manipulate the diet of animals and administer additives on a daily basis) or with grazing animals (using extensive farming systems, which are strongly influenced by environmental conditions).

124. Any novel feeding practice has to be supported by reliable results from laboratories, which is often a barrier in many countries. Since some feeding practices are expensive, it is likely that they will only be applied to the most profitable animals, which are mainly dairy cows. There is experimental evidence that adding too much of certain feed additives may have negative effects on animal digestion. As proposed by the IPCC (IPCC. 2007b), the inclusion of new pasture species needs to be assessed in order to find out the ecological consequences of introducing these new species. Introducing vegetal species into the diet of animals may result in changes in the manure composition and N release, which in turn may affect the levels of $N_2O$ emissions from manure. The rate of turnover into new species, the cost of pasture renewal and persistence of the new species within the species mix in the pasture can be barriers to widespread adaptation.

125. **Opportunities**: the effect of different practices considered part of this mitigation option depends on soil and climatic conditions, especially when dealing with grazing animals. Voluntary agreements, certificates for ‘clean production’ or ‘environmentally friendly production’ could be issued to farmers, allowing them to improve their market position in national or international markets.

126. **Co-benefits and the contribution to sustainable development**: reduced pressure on natural resources (such as soils, vegetation and water) allow a higher level of sustainability, as it lowers levels of soil erosion, desertification and/or over-grazing. There is potential for an increase in the profitability of livestock production systems.

### 3. Selection and breeding of high performance animals

127. **Mitigation potential**: for $CH_4$ emissions from enteric fermentation: 0.4–5 per cent for dairy cows; 0.6–7 per cent for beef cattle; 0.04–0.4 per cent for sheep; 1–3 per cent for dairy buffalo and 2–7 per cent for non-dairy buffalo (IPCC. 2007b).

128. **How to achieve**: this practice is most suitable as a medium-term approach, combined with an animal selection strategy based on the continuous improvement in the performance of animals (in terms of milk production, rate of weight gain, feed conversion, rate of protein absorption, etc.) within a farm herd. Cross-breeding can be beneficial in areas where higher productivity and resistance to diseases are required (NZ-MAF, 2008).

129. **Methodologies used to estimate emissions**: the changes in $CH_4$ emissions can be estimated using either tier 2 or tier 3 methods.

130. **Challenges**: selection and breeding of high performance animals requires investments in education and guidance for farmers or land managers to implement effectively any continuous selection programme. For breeding programmes, the main barriers are the availability of financial resources and the availability of animals with certified high genetic merit.

131. **Opportunities**: this strategy seems to be applicable to the most profitable animal production systems, which are usually dairy production systems; it could also be applied to beef cattle and sheep.

132. **Co-benefits and the contribution to sustainable development**: more productive animals could reduce pressure on natural resources (such as forages, soils and water), thus reducing the risk of over-grazing, soil erosion and soil degradation.

4. Dietary additives and specific agents

133. **Mitigation potential**: for $CH_4$ emissions from enteric fermentation: 0.3–1 per cent for dairy cows; 0.4–9 per cent for beef cattle; 0.02–0.4 per cent for sheep; 1–3 per cent for dairy buffalo and 0.2–1.2 per cent for non-dairy buffalo (IPCC. 2007b).

134. **How to achieve**: several dietary additives are commercially available and can be used by farmers.

135. **Methodologies used to estimate emissions**: $CH_4$ emissions can be estimated by following tier 2 methods, but preferably tier 3 methods should be used.

136. **Challenges**: the main barriers are: a lack of information on whether the reduction of emissions can be sustained over a long period of time (there is experimental evidence indicating an adaptive response by animals to the continuous use of dietary additives); the use of artificial chemicals or biological compounds has a negative affect on consumers; national regulations that increasingly control the use of certain dietary additives and specific agents, including a complete ban; and not enough information on the effects of the residues of such additives and agents in ecosystems, soils, water and tissues. Other barriers include: the lack of laboratory facilities; the lack of commercial availability of devices to measure enteric $CH_4$ emissions; and the high costs of some dietary additives and agents.

137. **Opportunities**: the development of safe dietary additives and agents would require close collaboration between all stakeholders, including governments, the private sector and non-governmental organizations (NGOs).

138. **Co-benefits and the contribution to sustainable development**: this strategy reduces pressure on natural resources (such as soils, vegetation and water). There is potential for an increase in the profitability of livestock production systems.

5. Hormone and enzyme manipulation

139. **Mitigation potential**: for $CH_4$ emissions from enteric fermentation, the mitigation potential is estimated to be 15 per cent when bovine somatotropin (bST) is used.

140. **How to achieve**: the use of hormonal implants and enzymes can improve animal performance and can lead to the reduction of emissions per unit of animal product. Hormonal implants and enzymes are already available and are used in cattle production in many countries.

141. **Methodologies used to estimate emissions**: the emissions of $CH_4$ from animals treated with hormonal implants can be estimated using tier 2 or tier 3 methods.

142. **Challenges**: the main barrier for the implementation of hormone and enzyme manipulation is the negative affect animal products that have undergone hormone and enzymatic manipulation have on consumers. In many countries this practice is banned in beef products.

143. **Opportunities**: there are no major opportunities for the use of this practice given the absence of safe hormones and/or enzymes that would not have a negative impact on human health.

144. **Co-benefits and contribution to sustainable development**: this system reduces pressure on natural resources (such as soils, vegetation and water) and creates a more sustainable pasture system. There is potential for an increase in the profitability of production systems.

### B. Future mitigation practices

145. Table 30 in the annex to this paper presents some future mitigation practices for livestock management that are currently being researched. For some of these mitigation practices, the research thus far has created products that are commercially available, but the application of these products as mitigation options has be fully assessed.

146. These future mitigation practices have the same objectives as current mitigation practices, that is to say: (i) to breed higher performance animals (using breeding, cloning and genetic manipulation techniques), (ii) to develop feeding practices (plant breeding programmes to produce new and improved forage species, including high efficient-N plants); (iii) to make new technological developments to reduce $CH_4$ formation in ruminant animals; (iv) additional practices for manure management; and (v) to use nitrification inhibitors in manure piles and soils.

147. Out of all of the aforementioned practices, pasture management practices seem to be the most promising because of their low technical and technological requirements. Practices that would result in genetically improved animals and forage plants; and new practices regarding manure management and the use of nitrification inhibitors seem to be the most probable new mitigation options to become available within the next decade. Practices linked to the use of new agents to modify the rumen ecosystem are long-term and would need to ensure that none of these new agents have negative impacts on human health.

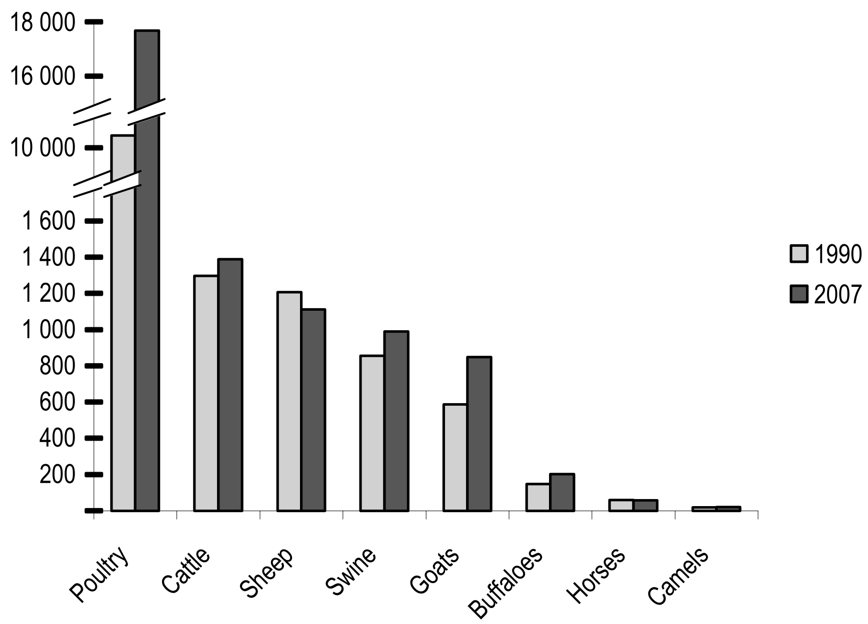
## VI. Case studies for livestock and manure management

### A. Introduction

148. On a global scale, the most important animal species, in terms of number of animals are poultry, cattle, sheep and swine (see figure 8). The changes in animal populations between 1990 and 2005 are also reflected in the meat production data shown in figure 9. Between 1990 and 2007, meat production increased, with swine and poultry accounting for the majority of this increase.

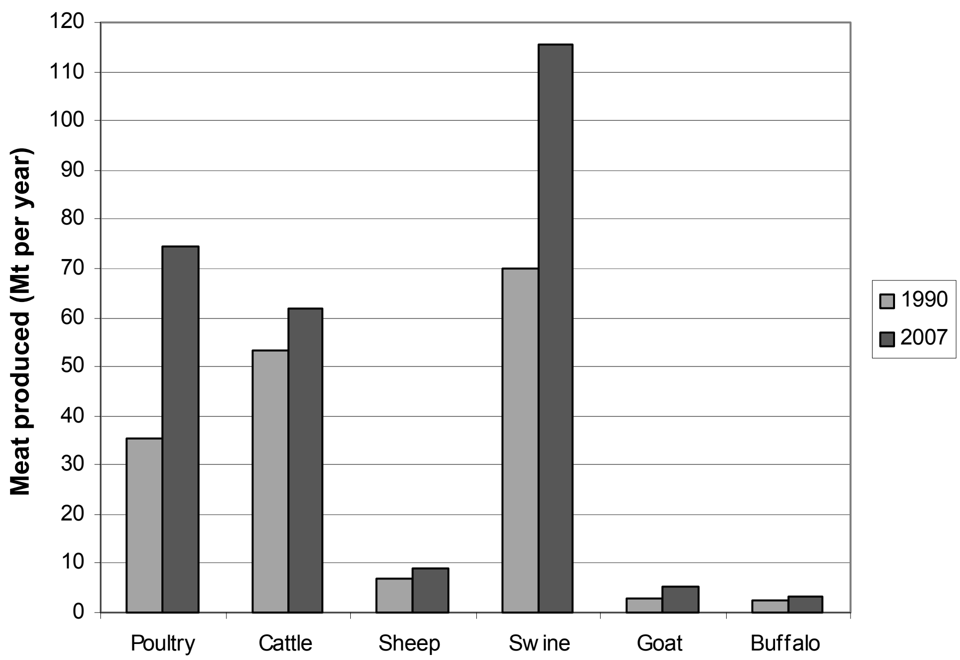
149. As shown in figure 10, the main cattle producing regions are South America and Southern Asia, which together account for about 43 per cent of the total cattle population; the main sheep producers are Oceania (mainly New Zealand), Eastern Europe and Southern and Eastern Asia; swine population is concentrated in Eastern Asia (mainly China), with almost half of the world population, followed by Eastern Europe, with 15 per cent; the main poultry producers are Eastern Asia, North America and Eastern Europe; and the largest goat population can be found in Southern and Eastern Asia (53 per cent of total population) followed by Western, Eastern and Northern Africa.

**Figure 8. Global population of the most important animal species in 1990 and 2007**
*(heads of animals)*




*Source*: Food and Agriculture Organization of the United Nations. FAOSTAT database <http://faostat.fao.org>.

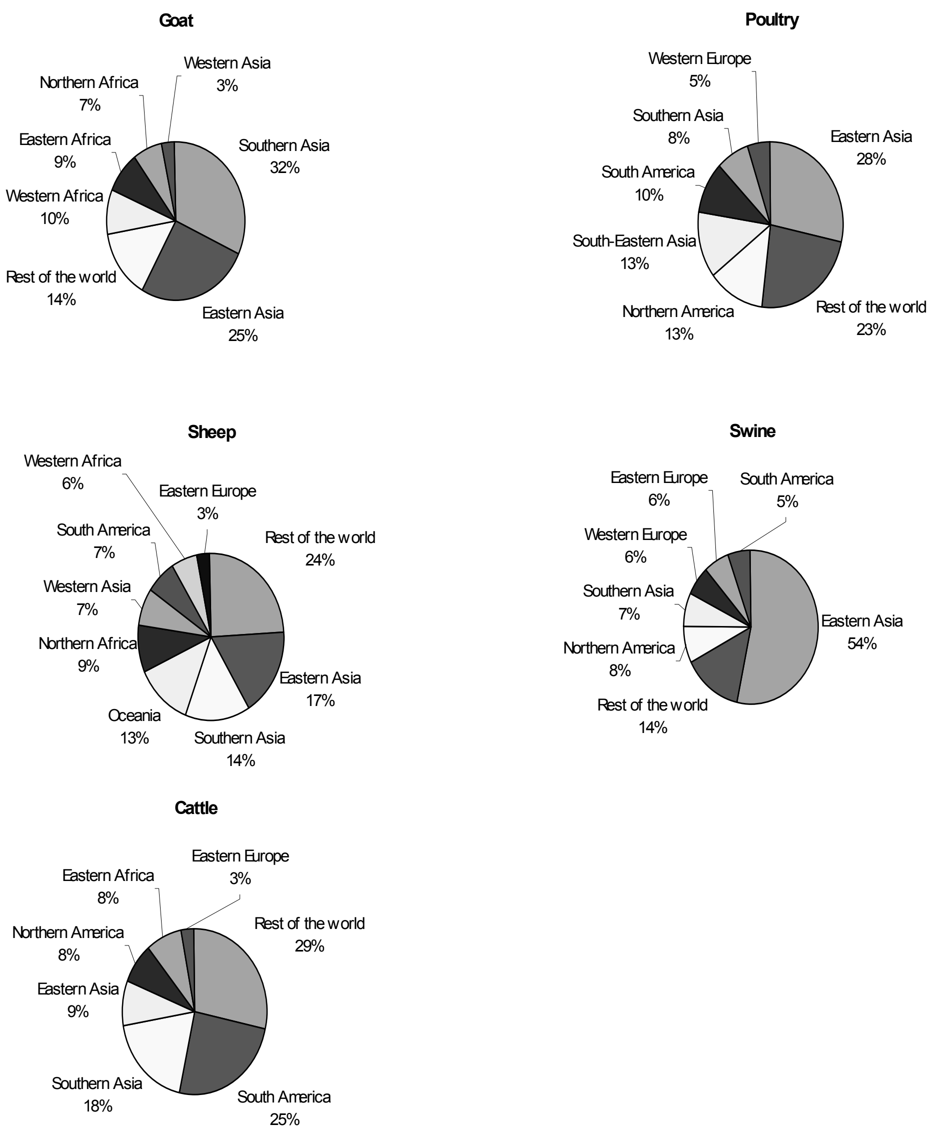
**Figure 9. Global meat production in 1990 and 2007, by animal species**




*Source*: Food and Agriculture Organization of the United Nations. FAOSTAT database <http://faostat.fao.org>.

150. Meat production data from FAOSTAT (2008) follow the distribution of the animal species but the relative proportion of each in the total change according to regional productivity, a factor driven by national circumstances (see table 5).

**Figure 10. Regional distribution of farmed animals in 2007, by species**




*Source*: Food and Agriculture Organization of the United Nations. FAOSTAT database <http://faostat.fao.org>.

**Table 5. Relative contributions of the world regions to meat production**
*(per cent)*

| Region | Cattle | Buffalo | Swine | Sheep | Goat | Chicken | All species |
|---|---|---|---|---|---|---|---|
| **Africa** | 7.48 | 8.43 | 0.71 | 13.38 | 18.15 | 4.56 | 4.37 |
| Eastern Africa | 2.51 | 0 | 0.22 | 2.19 | 4.53 | 0.52 | 1.03 |
| Middle Africa | 0.57 | 0 | 0.08 | 0.43 | 1.52 | 0.09 | 0.29 |
| Northern Africa | 1.62 | 8.43 | 0 | 6.48 | 4.88 | 1.9 | 1.37 |
| Southern Africa | 1.46 | 0 | 0.14 | 1.46 | 1 | 1.34 | 0.8 |
| Western Africa | 1.32 | 0 | 0.28 | 2.81 | 6.22 | 0.71 | 0.89 |
| **Americas** | 47.05 | 0 | 15.6 | 4.67 | 3.2 | 45.64 | 30.3 |
| Northern America | 21.53 | 0 | 10.26 | 1.14 | 0.42 | 22.92 | 16.18 |
| Central America | 3.32 | 0 | 1.14 | 0.58 | 0.89 | 4.31 | 0.71 |
| Caribbean | 0.33 | 0 | 0.21 | 0.1 | 0.23 | 0.77 | 2.38 |
| South America | 21.86 | 0 | 3.98 | 2.86 | 1.65 | 17.64 | 0.37 |
| **Asia** | 22.65 | 91.53 | 60.99 | 53.79 | 75.75 | 33.58 | 11.37 |
| Central Asia | 1.92 | 0 | 0.22 | 4.07 | 0.47 | 0.13 | 44.85 |
| Eastern Asia | 13.05 | 11.26 | 54.91 | 30.06 | 44.83 | 17.1 | 33.54 |
| Southern Asia | 4.26 | 69.2 | 0.45 | 10.01 | 24.59 | 5.84 | 4.2 |
| Southeastern Asia | 1.92 | 10.88 | 5.3 | 1.02 | 2.55 | 3.68 | 4.68 |
| Western Asia | 1.50 | 0.18 | 0.1 | 8.63 | 3.31 | 6.83 | 1.72 |
| **Europe** | 18.12 | 0.04 | 22.26 | 14.57 | 2.51 | 14.9 | 18.35 |
| Eastern Europe | 5.49 | 0.01 | 5.67 | 2.6 | 0.73 | 5.8 | 5.26 |
| Northern Europe | 3.17 | 0 | 2.99 | 5.01 | 0.01 | 2.6 | 2.84 |
| Southern Europe | 3.57 | 0.03 | 5.18 | 5.03 | 1.59 | 3.04 | 4.12 |
| Western Europe | 5.89 | 0 | 8.42 | 1.94 | 0.18 | 3.46 | 6.14 |
| **Oceania** | 4.71 | 0 | 0.45 | 13.59 | 0.4 | 1.32 | 2.13 |
| Australia and New Zealand | 4.68 | 0 | 0.37 | 13.59 | 0.37 | 1.29 | 1.96 |

*Source*: Food and Agriculture Organization of the United Nations. FAOSTAT database <http://faostat.fao.org>.

151. Table 6 provides the values of animal productivity, calculated as the total annual meat production divided by the total number of animals. For cattle, high values (e.g. North America, Southern Europe, Western Europe, Northern Europe and Central Asia) reflect the intensity of the production system and provide an indication for the presence of animals with high genetic merits and/or high feeding quality, while low values (Southern Asia and almost all of Africa, except for Southern Africa) reflect low quality forage and the presence of low productivity animals.

152. Values for sheep productivity also reflect differences among the world regions, which are consistent with the findings for cattle: high values for Northern America, Northern Europe and Western Europe and low values in regions dominated by developing countries (Africa, the Caribbean and South America). In relation to goats, low values reflect the production in semi-arid regions with the only exception of Oceania, where they are intensively managed, leading to high productivity levels. Productivity values for swine are related to confinement or grazing conditions; high genetic merits of animals; and diet quality. The higher the productivity value, the higher the proportion of confined high merit animals that are fed with high quality diet.

**Table 6. Productivity of cattle, sheep, goats and swine, 2007**
*(kilogram per head per year)*

| Region | Cattle | Sheep | Goats | Swine |
|---|---|---|---|---|
| Eastern Africa | 14.21 | 3.45 | 3.13 | 38.88 |
| Middle Africa | 16.58 | 4.44 | 3.9 | 20.83 |
| Northern Africa | 20.44 | 5.59 | 4.33 | 48.95 |
| Southern Africa | 44.21 | 4.48 | 4.54 | 87.96 |
| Western Africa | 16.07 | 3.63 | 3.93 | 26.55 |
| Northern America | 119.85 | 14.29 | 7.33 | 156.56 |
| Central America | 48.95 | 6.6 | 5.06 | 74.89 |
| Caribbean | 24.24 | 2.89 | 3.02 | 66.37 |
| South America | 39.2 | 3.49 | 3.39 | 85.78 |
| Central Asia | 69.3 | 8.21 | 3.33 | 171.78 |
| Eastern Asia | 63.77 | 14.3 | 10.68 | 120.88 |
| Southern Asia | 10.32 | 5.73 | 4.65 | 34.14 |
| Southeastern Asia | 25.97 | 8.55 | 5.62 | 88.52 |
| Western Asia | 44.74 | 9.26 | 6.57 | 84.99 |
| Eastern Europe | 77.65 | 7.51 | 8.14 | 105.82 |
| Northern Europe | 84.33 | 10.37 | 3.32 | 133.08 |
| Southern Europe | 121.23 | 9.19 | 7.19 | 130.42 |
| Western Europe | 86.63 | 12.99 | 4.64 | 151.67 |
| Oceania | 75.07 | 8.63 | 21.49 | 97.16 |
| **World** | **44.53** | **7.99** | **6.05** | **134.78** |

*Source*: Food and Agriculture Organization of the United Nations. FAOSTAT database <http://faostat.fao.org>.
*Note*: Although not all animals are used for meat production, this number has been utilized here due to the lack of the necessary statistical information.

## B. Beef cattle

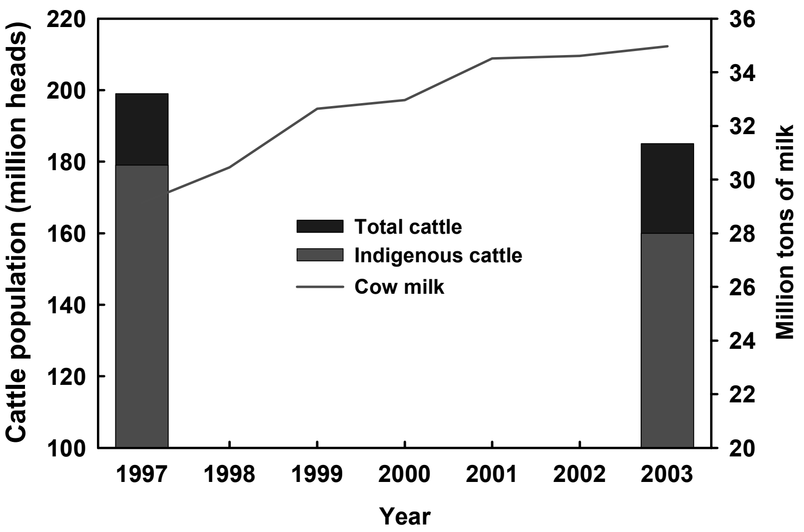
### 1. Livestock systems

153. According to the 2003 Livestock Census released by the Government of India Department of Animal Husbandry, Dairying and Fisheries (DAHD, 2003), the number of cattle in India amounted to about 185 million head, a decrease of 7 per cent compared to the 1997 data. Indigenous cattle population represented 89 per cent in 1997 and 75.4 per cent in 2003 (see figure 11). About 70 per cent of the country's livestock is owned by small and marginal farmers, and landless labourers.

154. Less than 4 per cent of the land in India is used for pasture and grazing. Animals either subsist on poor quality grasses or are stall-fed principally on crop residues. The deficit for feed and fodder in the country are of the order of 22 per cent for dry fodder and 62 per cent for green fodder (Sirohi et al., 2007). For crossbred dairy cows, oil-seed cakes provide the basis for richer diets, while resulting in higher emissions of $CH_4$ and $N_2O$ per head.

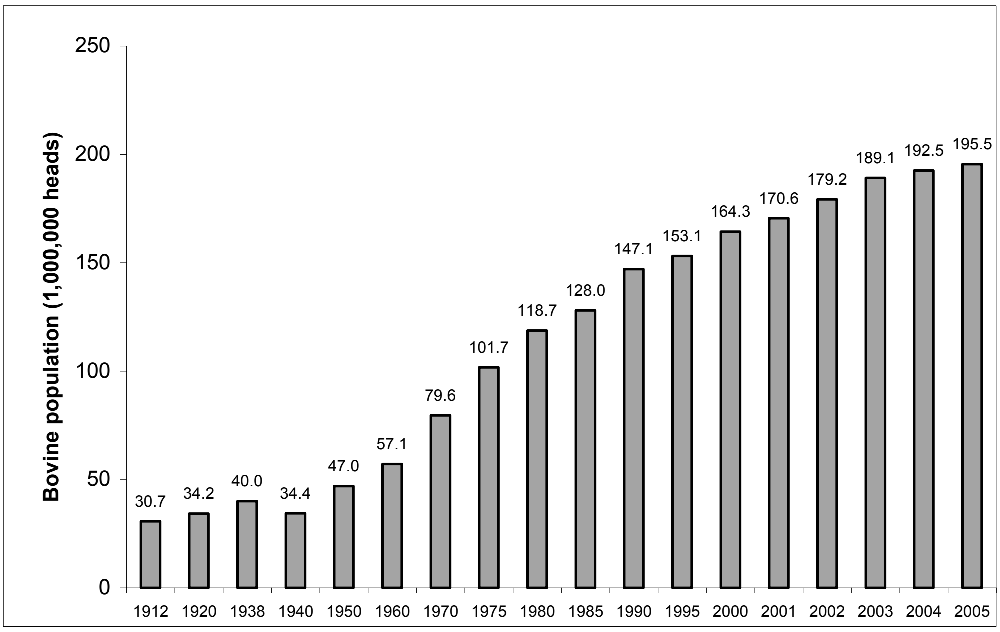
155. Brazil has the world's second largest cattle herd with about 165 million heads (FNP, 2005), representing about 16.3 per cent of the world total. The main producing states are: the Middle-West Region (Mato Grosso do Sul, Mato Grosso and Goiás), Minas Gerais and São Paulo (Southeast region), Rio Grande do Sul (South region) and Bahia (Northeast) states. Over the course of the last century the country has seen a steady growth in bovine population (figure 12) and beef exports.

**Figure 11. Total and indigenous cattle population and total milk produced in India in 1997 and 2003**




*Source*: Department of Animal Husbandry, Dairying and Fisheries, Ministry of Agriculture, Government of India. *Annual report 2002 and 2003* <http://dahd.nic.in>
*Note*: Based on the Census of 1997 and 2003 in India.

**Figure 12. Growth of bovine population in Brazil, 1912–2005**




*Sources*: Methane to Markets Partnership, 2006. *Brazil Profile for Animal Waste Management*. Washington, DC: Methane to Markets Partnership <http://www.methanetomarkets.org>.

156. In Brazil, cattle raising systems range from extensively managed systems, with low production, to intensive systems. Pastures allow for a stocking rate of 0.5 animal units per hectare (AU/ha) (low productivity), and up to 0.7 AU/ha (high productivity) in the rainy season. The tendency is to improve the mean stocking rate up to 1 AU/ha, although for some regions intensification practices exist that enable a stocking rate of 5 to 6 AU/ha/year, through the feeding on tropical grasses and chopped sugarcane plus urea.

157. The predominant cattle type is the Zebu and its crossbreeds (about 80 per cent of beef cattle herd and 64 per cent of total cattle herd), which are more suited for tropical conditions, since they have lower maintenance requirements and digest more efficiently low quality forage. About 5 per cent of slaughter animals are finished in confinement, and 95 per cent under grazing systems.

158. Beef production efficiency is expected to increase in Brazil due to: an anticipated increase in the reproductive efficiency of the beef cow herd thanks to improved pastures and mineral supplementation; a lowering age at slaughter with the adoption of improved pasture species, mineral and protein supplements on pasture and increased adoption of feedlots; increased milk production per cow reflecting an overall improvement in management, as well as a better animal genetic.

### 2. Quantification of emissions in Brazil

159. Studies in which measurements of $CH_4$ emissions by ruminants are being performed are very recent, and few of them are related to $CH_4$ mitigation strategies. Measurements of methane emissions from dairy and beef cattle in the Southeast region of Brazil (Johnson & Johnson, 1995) have been carried out under different grazing management systems and diets. These measurements have shown higher methane emission rates, of about 5 per cent for Zebu crossbred when dry matter (DM) intake was stimulated by a complementary grain concentrate (with an increase of about 20 per cent). When forage quality diminishes, the decrease of DM intake reduces methane emissions per head, but increases relative to the unit of product.

160. The use of sugarcane leads to reductions in methane emission per kg of DM intake and gross energy intake, when feed intake is improved by using urea or grain concentrate. Experiments with sorghum silage and an increasing substitution of DM by grain concentrate showed a peak methane emission at around 36.6 per cent of DM as concentrate.

161. Methane emissions from grazing beef cattle are dependent on the season, reflecting the nutritional conditions of grazing during wet and dry conditions. Experiments with Nelore cattle have shown that the conversion rate of methane or loss of digestible energy in the spring (10.6 per cent) was lower than that recorded in winter (11.9 per cent). Also, $CH_4$ emissions per kg of live weight seems to have an inverse relation to live weight, probably because of a higher relation of viscera to live weight in young animals, besides a higher metabolic activity.

162. A recent study indicates a potential effect of condensed tannins as an inhibitor of methanogenesis in the rumen, but the mechanisms involved in the process are not yet well understood in relation to the level of 20 per cent of inclusion with yeast.

163. Recent studies suggest that there is a potential for mitigation based on: measures that include the improvement of pastures, applying of mineral and protein supplements to pasture and increased adoption of feedlots. However, a complete GHG accounting must be performed to capture the net benefit of each practice taking also into account that nitrogen inputs in soils, through the use of fertilizers, can produce more nitrous oxide emissions from pastureland systems, which could offset the reduction of methane by ruminants.

### 3. Greenhouse gas emissions in India

164. In 2000, methane and nitrous oxide contributed 27 per cent and 7 per cent, respectively, to India's $CO_2$ equivalent GHG emissions (Garg et al., 2003), of which agriculture- and livestock-related emissions contribute above 65 per cent of $CH_4$ emissions and more than 90 per cent of $N_2O$ emissions. The majority of $CH_4$ emissions come from working male and milking female bovines. Male indigenous cattle emit higher methane than female indigenous cattle, but the opposite was observed for crossbred cattle.

165. Regarding $N_2O$ emissions from livestock in India about 5 per cent of the overall $N_2O$ emissions in the country come from livestock excretions (Garg et al., 2004). The fact that a large proportion of cattle herd is kept in low quality pasture in an extensive system means that most of the excreta produced is land dispersed. The low quality diet in India means a relatively smaller proportion of N in cattle urine (Oenema et al., 2005), resulting in relatively lower $N_2O$ emissions from cattle excreta. However, a large share of cattle dung on the Indian continent is gathered for fuel (Smil, 1999), that means about 0.7 per cent of the N in dung is released as $N_2O$ after burning (Eggleston et al., 2006).

166. The improvement in cattle performance in India, due to regional government programmes is already resulting in a significant milk increase, along with a reduction in bovine numbers (GOI, Agriculture Report, 2008). Sirohi et al. (2007) presented several cost-effective possibilities to mitigate methane emissions from cattle in India (table 7).

**Table 7. Cost analysis of methane emissions reduction strategies for adult, indigenous and crossbred dairy cows in India**

| Diet additive | Annual cost of diet additive or supplementation | Annual methane reduction | Gross cost of reduction | Increase returns from milk production | Net cost of reduction |
|---|---|---|---|---|---|
| | EUR | Per cent | EUR/kg $CH_4$ | EUR | EUR/kg $CH_4$ |
| *Indigenous cow at 36 kg $CH_4$ head$^{-1}$* | | | | | |
| Molasses-urea | 13.0 | 11 | 3.3 | 6.9 | 1.5 |
| Concentrate | 40.2 | 15 | 7.4 | 6.9 | 6.1 |
| Ionophore | | | | | |
| Rumensin[a] | 0.27 | 20 | 0.04 | 5 | -0.4 |
| Pure Monensin[b] | 651.8 | 20 | 90.5 | 5 | 90 |
| *Crossbred cow at 39 kg $CH_4$ head$^{-1}$* | | | | | |
| Concentrate | 100.4 | 15 | 17.0 | 141.6 | -7.0 |
| Ionophore | | | | | |
| Rumensin | 0.27 | 22 | 0.03 | 14.2 | -1.6 |
| Pure Monensin | 651.8 | 22 | 75.8 | 14.2 | 74.1 |

[a] Monensin Premix; [b] Monensin sodium salt.

*Source*: Adapted from Sirohi S., Michaelowa A and Sirohi SK. 2007. *Mitigation options for enteric methane emissions from dairy animals: an evaluation for potential CDM projects in India. Mitigation and Adaptation Strategies for Global Change, v. 12 (2)*: pp.259–274.

167. Given that the agriculture sector is the dominant source of $CH_4$ and $N_2O$ emissions in India, involving the Indian farmers in the innovation process of mitigating emissions from the sector is a big challenge, considering the regional spread of cattle sub-categories, variation in management, large number of farmers involved and small land holdings. If the initial thrust comes from the widespread livestock extension services and it is linked with improving cattle production and mitigation it may lead to a win-win situation (Garg et al., 2004). While cereals–pulses–oil seeds–vegetables–dairy integrated systems in India can increase farm income by 47.8 per cent (Kumar et al., 2002), the improved diet of dairy cattle can result in significant mitigation of methane per production unit. However, it is not easily estimated how changes in $N_2O$ emissions would affect the overall GHG balance.

168. Uncertainties in the emissions estimates are large, especially because of the lack of accurate data regarding N excretion and the management of animal waste. The expected increases in $N_2O$ emissions following a projected increase in animal numbers in 2030 seem to be much larger compared to the potential decreases in $N_2O$ emissions through feasible mitigation measures. The best mitigation strategy for confined animals seems to be the anaerobic digestion of stored animal waste and the improvement of the N use efficiency in all the pasture and animal life cycle (Oenema et al., 2005).

169. The implementation of simple strategies can bring significant results in terms of GHG mitigation and animal production. In this regard, considering the large cattle population in India, clean development mechanism projects can provide benefits in terms of emissions reductions and sustainable development, as well as provision of economic resources and technology that will help boost livestock productivity in India.

## C. Swine

### 1. Biogas production in China

170. Biogas production and use represents one of the most promising options to reduce methane emissions from the agriculture sector in China. Biogas has been studied since 1920, mainly due to its environmental (disposal of manure) and sanitary issues. By the early 1980s, the Chinese government considered biogas production an effective and rational use of natural resources in rural areas. Until 1986, there were 453,000 digesters being used in the country. With the improvement of digesters and better technologies in the fermentation processes, scientific construction, and managing biogas digesters, there was an observed increase in the use of biogas in the country. By the end of 2000, there were 9.8 million household digesters.

171. In 2002, China's 2003–2010 National Rural Biogas Construction Plan was announced proposing an increase in biogas use by 11 million to a total of 20 million households by 2005, in order to make one in ten farmers' households a biogas user. By 2010, it is expected that China would increase biogas-using households by a further 31 million to a total of 50 million. From 2003, a government subsidy of 1,000 Yuan (about USD 150) is provided for each biogas digester.

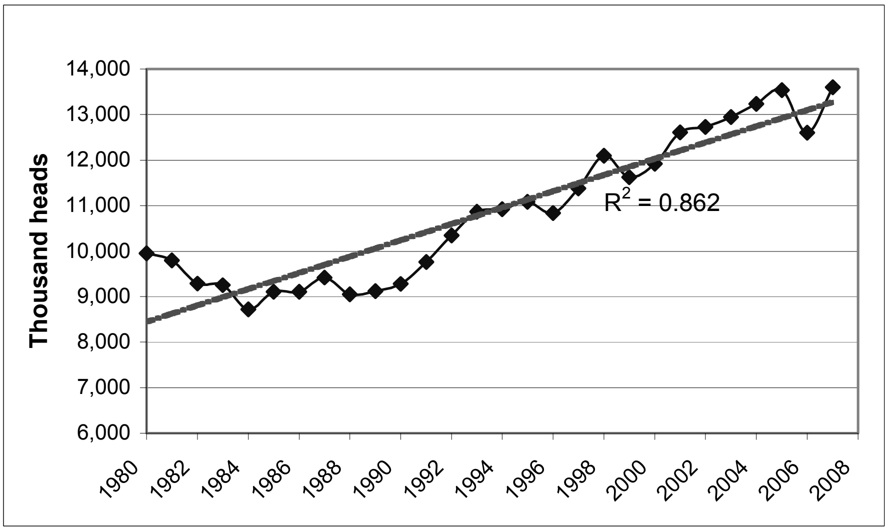
172. At the end of 2005, China had 17 million digesters with an annual production of around 6.5 billion cubic metres of biogas, mostly in rural areas. China projects an annual production of biogas of 25 billion cubic metres by 2020, which will provide energy to one quarter of households in rural areas.

173. Given the growth in the swine production sector, there is large potential for the increase in biogas utilization (also taking into account the potential for CDM projects in this area). In addition to animal waste, China also produces large amounts of straw and stalk biomass from croplands (650 million tons of biomass/year). Owing to efforts of scientific institutes and regional corporations, the technology for producing biogas using biomass has progressed significantly and is now widely available in the country. An appropriate legal framework will constitute an important factor to encourage diffusion of the adoption of biogas technology. To maximize the benefits of biogas as an energy source, China also needs advanced technologies to purify and compress methane for use in rural vehicles and machinery.

### 2. Swine management in Denmark

174. Enteric methane emissions from the swine population in Denmark increased by 45 per cent in the period 1990–2006 (from 213 Gigagrams $CO_2$ eq per year to 309 Gigagrams $CO_2$ eq per year ). This increase was the result of an expansion of the swine population (increase of 38 per cent in the same period) and an increase in the per capita emissions due to increased efficiency in animal performance (3 per cent increase from 1990 to 2006). However, the trend changes when animal efficiency is taken into consideration. In the period 1990–2006, the typical animal mass increased by 11.7 per cent (from 72.7 kg/hd to 81.2 kg/hd). This means that, although emissions per capita increased by 3 per cent, the emissions rate per unit of live weight unit decreased by 7.8 per cent (figure 13).

**Figure 13. Swine population in Denmark**




*Source*: Food and Agriculture Organization of the United Nations. FAOSTAT database <http://faostat.fao.org>.

175. The increasing efficiency of the swine production systems is also reflected by the excretion of nitrogen by the animals. According to information reported in the Danish GHG inventories, each animal releases (on average) 9.9 kg N per year, with a decreasing trend from 11.6 kg N per year in 1990 to 8.6 kg N per year in 2006.

176. As stated in its fourth National Communication, Denmark's climate policy has been developed in collaboration with the different societal actors, taking into consideration the requirements of international climate policy and the results of related scientific research. Measures within the agriculture sector that deal with GHG emissions from swine include the Ammonia Action Plan, an Amended Statutory Order on Manure, and the Action Plan for Joint Biogas Plants.

177. Measures under the Ammonia Action Plan include: optimization of manure handling during housing for cattle, pigs, poultry and fur animals; rules on covering storage facilities for solid manure and slurry tanks; ban on surface spreading and reduction of the time from field application of manure to incorporation; ban on ammonia treatment of straw. The Ammonia Action Plan, active since 2001, in conjunction with action plans for the aquatic environment, intends to reduce ammonia emission by 15–20,000 t N per year; thus the expected reduction in nitrous oxide emissions is 34,000 t $CO_2$–eq per year by 2010.

178. In general, pig farmers have responded positively to imposed regulations (for example, permits are required from the authorities before new pig production units can be built or existing units expanded). Reductions of emissions have resulted from the use of slurry from pig farms on arable lands (having progressively substituted significant amounts of artificial fertilizers). Furthermore, leakage of nitrogen from Danish crop farming to the aquatic environment has fallen by almost 50 per cent in recent years.[9]

179. The Action Plan for Joint Biogas Plants is estimated to lead to annual emission reductions of about 0.25 million tonnes $CO_2$ eq. According to Sander,[10] in 2007 174 biogas plants were operational in Denmark, producing a total of 1.1 TWh and 4,000 TJ of heat. Eighty of them were manure-based and 64 were sewage sludge-based. Manure-based biogas plants produce around 60 per cent of the total biogas of the country; one third corresponds to centralized plants and the other two thirds, to farm scale plants.

[9] See <www.dbmc.co.uk/dowloads/Danish-Pig-Producers-and-the-Environment.Aug08.pdf>.
[10] See <www.sgc.se/nordicbiogas/resources/Bruno_Sander_Nielsen.pdf>.

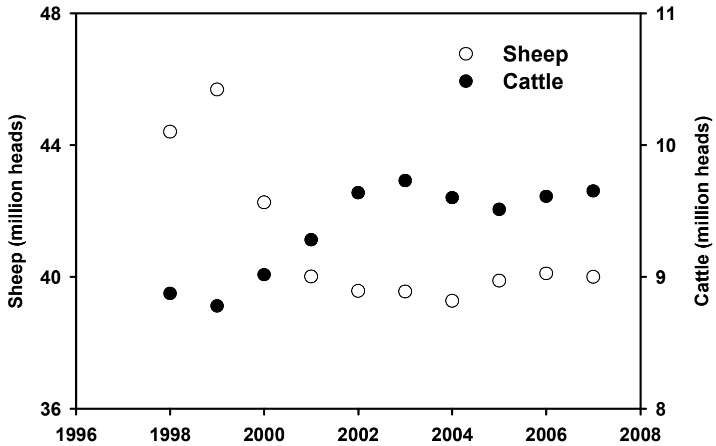
180. The biogas production in Denmark is expected to triple by 2025, leading to enhanced societal benefits (GHG emission reductions, improved aquatic environment quality, odour abatement, pathogen reduction, energy security and biomass utilization) and additional sources of income for farmers.

## D. Sheep

Land use and production systems

181. Enteric fermentation is one of the largest sources of $CH_4$ emissions in New Zealand accounting for about 96 per cent of the total national anthropogenic $CH_4$ emissions (Saggar et al, 2008). Between 1998 and 2007, sheep population declined by 10 per cent (figure 14) resulting in a proportionate decrease in $CH_4$ and $N_2O$ emissions from this livestock category.

**Figure 14. Variations in sheep and cattle populations in New Zealand, 1997–2007**




*Source*: Food and Agriculture Organization of the United Nations. FAOSTAT database <http://faostat.fao.org>.
*Note:* Cattle figures include beef and dairy cattle

182. Most of the $N_2O$ emitted in New Zealand comes from grazed grasslands, as a result of large nitrogen inputs from the dung and urine deposited by grazing animals. The second source is from N fertiliser and indirectly from fixed $N_2$ that mineralizes from legume residues in mixed pastures. Sheep are not housed and all faecal material is deposited directly onto pastures, contributing to $N_2O$ fluxes. Measures of soil $N_2O$ emissions from sheep grazed areas have been in the range of 5.8–7.1 kg $N_2O$ per ha per year, slightly above the estimates using models 8.6–12.7 kg $N_2O$ per ha per year (Saggar et al., 2008). Saggar et al. (2007) measured $N_2O$ fluxes at the soil surface of a sheep-grazed pasture over a 20-month period. Measured annual $N_2O$ emissions were estimated to be 5.9–3.5 kg $N_2O$ per ha per year, with 11.6 g $N_2O$ per ha per day on average, almost two times that observed on ungrazed sites.

183. In New Zealand, the decrease in sheep population observed over the last decade was governed by market forces. Therefore, mitigation strategies need to come from forage, animal breeding and management, along with animal diet changes, for example the addition of probiotics, propionate precursors, ionophores etc..

184. Feeding sheep with forage species from temperate regions helps in improving their live weight gain, wool production and reproductive efficiency and in reducing the impact of gastro-intestinal parasitism. However, some constraints for animal health require careful consideration of the best legume–grass combination (Waghorn et al., 2008). In New Zealand, the use of N transformation inhibitors is one of the approaches that is showing promise as a mitigation tool for controlling N dynamics in pasture soils (Saggar et al, 2008).

185. Improving animal nutrition through either management or diet will reduce methane emissions per unit of output. Improvements in animal genetics may lead to similar results. However, given the high degree of development of sheep farming in New Zealand there is limited space for further improvement through these practices which may, furthermore, result in more emissions per animal.

186. For more intensified sheep production systems in New Zealand, the best prospect is to modify the rumen flora and rumen metabolism. The use of supplements or even additives, elimination of protozoa from the rumen (defaunation), increase in acetogens, use of probiotics and ionosphores, and immunization are promising techniques for sheep. However, the fact that sheep are housed only a few times per year means that technologies that require regular application will have limited value.

187. Immunization against $CH_4$ producers in rumen is a potential strategy to halt livestock emissions. Sheep immunised with an anti-methanogen vaccine may emit significantly lower methane emissions compared to non-immunized sheep (Wright et al, 2004). It is the most promising approach because it may be applicable to all classes of livestock; however, more research is needed to demonstrate its effectiveness and it will need to meet all regulating barriers.

188. Individually none of the options outlined above provides a simple, universally applicable mitigation technology.

## E. Goats

189. Despite the fact that goats are present on virtually all continents, their ability to survive in harsh environments has resulted in their breeding in subsistence agriculture systems of poorer regions. The largest numbers of goats are found in Asia and Africa (FAOSTAT, 2008), where goat production is confined in small farms. Goats in Africa are found mostly in sub-Saharan countries, where they are kept under grazing or mixed systems, the latter comprising of grasses, stover, groundnut hay, etc. (Herrero et al., 2008). According to projections by Herrero et al. (2008) the goat population in Africa by 2030 will increase by 59 per cent (table 8).

**Table 8. Goat population in different environments of Africa, estimated and projected, 2000 and 2030**

| Environment | 2000 | 2030 | Variation (%) |
|---|---|---|---|
| Arid | 17.2 | 27.2 | 58 |
| Humid | 3.4 | 6.7 | 97 |
| Temperate | 1.3 | 0.9 | –31 |
| Other | 1.6 | 2.6 | 63 |
| **Total** | **23.4** | **37.3** | **59** |

*Source*: Herrero M PK, Thornton R, Kruska R and Reid RS. 2008. Systems dynamics and the spatial distribution of methane emissions from African domestic ruminants to 2030. *Agriculture, Ecosystems & Environment,* 126*:* pp.122–137.

190. Methane emissions from goats in Africa were estimated to be about 567 Gigagrams $CH_4$ for the year 2000 (Herrero et al.; 2008). Methane emissions from dung deposited on soil are of less importance, and they are estimated at 17 Gigagrams in 2000 and projected at 27 Gigagrams in 2030. Manure storage represents a very small percentage of the overall emissions as most of the excreta are directly applied on soils or used for combustion (Vergé et al., 2007).

191. According to Reid et al. (2004), a reduction in pastoral areas is expected in the future, partially due to climate change, which will make a large area of Africa drier. Additionally, pastoral land pressure for growing grain crops is also expected, resulting in more livestock intensification systems, such as confinement, and subsequent increases in GHG emissions.

192. Mitigation of methane emissions by ruminants can be partially achieved by improvement in diet (Vergé et al., 2007), which would also increase the production of goat products such as skin, milk and meat. In this case, supplementation to low quality pasture could come from local species such as leaves and pods of Acacia senegal (L.) Willd and leaves of Pterocarpus lucens Lepr. Ex Guill & Perrott, both well browsed by goats, and with high crude protein, good intake characteristics and high nutrient digestibility (Sanon et al., 2008). Improvement of pastures will impact C sequestration and improve the quality of the forage, also having an impact on methane emissions. Breeding animals that are resistant to diseases and tolerant to environmental stresses would also lead to methane emissions reductions, mainly through increased animal productivity. Diet additives are available to reduce methane formation in rumen; however, developing the logistics to implement a strategy using this practice is not easily achievable.

193. Any strategy to improve mitigation schemes in Africa will require either the establishment of new or the improvement of existing infrastructure. This will require the active involvement of governments, which can use various approaches, including incentives, subsidy tax schemes as well as incentives for the use of carbon credits (Reid et al., 2004).

# VII. Mitigation practices for crops and soils

## A. Current potential mitigation practices

194. The following sections discuss mitigation practices for crops and soils in detail by providing: (i) the relative mitigation potential of each practice per unit of production and the conditions in which the practice may be applicable; (ii) the actions, mechanisms or best practices that are involved in achieving the target abatement; (iii) the methodologies to estimate emissions, including case studies of countries' capacity to measure, monitor and address emissions from crops and land use; (iv) the challenges or barriers that may occur in implementing the practice, including the knowledge gaps or needs to be addressed to improve the practice; (v) the opportunities that can be seized in implementing the mitigation practice, including its feasibility, opportunity cost and cost-effectiveness; and (vi) the co-benefits and potential implications of the mitigation practice to sustainable development. Summary information for all these practices is provided in table 30 in the annex.

### 1. Cropland management: agronomy

195. **Mitigation potential**: The potential of this mitigation practice to sequester C and reduce $N_2O$ emissions under different climate zones is shown in table 9.

**Table 9. Mitigation potential in croplands**

| Climate zone | $CO_2$ (t $CO_2$ $ha^{-1}$ $yr^{-1}$) | $N_2O$ (t $CO_2$ eq $ha^{-1}$ $yr^{-1}$) |
|---|---|---|
| Cool-dry and warm-dry | 0.29 (0.07 – 0.51) | 0.10 (0.0 – 0.20) |
| Cool-moist and warm-moist | 0.88 (0.51 – 1.25) | 0.10 (0.0 – 0.20) |

*Source*: IPCC. 2007b. *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmetal Panel on Climate Change.* Cambridge University Press, Cambridge, United Kingdom and New York, New York, United States.
*Note*: Values in parentheses correspond to low and high mitigation potential. Positive values represent $CO_2$ uptake, which increases the soil carbon stock, or a reduction in emissions of $N_2O$.

196. **How to achieve**: This mitigation practice can be achieved by improving agronomic practices that increase yields and generate higher inputs of C residue, which will lead to increased soil C storage (Follet et al., 2001). Examples of such practices include: using improved crop varieties; extending crop rotations, notably those with perennial crops that allocate more C below ground; and avoiding or reducing use of bare (unplanted) fallow (Freibauer et al., 2004; Lal, 2003, Lal, 2004a; Smith, 2004a, Smith, 2004b; and West and Post, 2002).

197. Another group of agronomic practices are those that provide temporary vegetative cover between successive agricultural crops, or between rows of tree or vine crops. These ‘catch’ or ‘cover’ crops add C to soils (Barthès et al., 2004; Freibauer et al., 2004), avoid erosion and may also extract forms of N available for plants from soils, thereby reducing $N_2O$ emissions.

198. **Methodologies to estimate emissions**: The method for estimating change in C stocks in soils in cropland is provided in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (hereinafter referred to as the 2006 IPCC Guidelines), volume 4 chapter 5. For $N_2O$ emissions, the generic methodologies adopted for managed soils, including indirect $N_2O$ emissions from additions of N to land, due to deposition and leaching, are provided in chapter 11 of the 2006 IPCC Guidelines.

199. **Challenges**: If this practice involves the use of improved crop varieties, with a view to increasing yield and biomass as C residue input, it will be a challenge to manage the fertilizer N requirement by the plants so as not to offset gains in C with the emission of $N_2O$ from fertilizer application.

200. The transaction costs for this type of mitigation project may create a serious entry barrier for smallholders in developing countries. For $N_2O$, the uncertainty involved and the substantial effect of variability between seasons and locations in the complex biological and ecological processes for measuring $N_2O$ emissions will be a challenge. For both gases, measurement and monitoring for this type of project might still be costly. There is a need to design the management practice taking into account long-term goals for maintaining C stocks or avoiding the reversal of the C stocks sequestered. The selection of an appropriate baseline to measure management-induced soil C changes may be an obstacle in designing some mitigation projects.

201. **Opportunities**: adopting cropping systems with reduced reliance on fertilizers and other inputs would reduce farming costs.

202. **Co-benefits/contribution to sustainable development**: This mitigation practice would contribute to the increase in productivity (food security) from the application of improved agronomic practices that increases yields. The practice will improve soil quality due to increased soil C storage from higher inputs of C residue and therefore prevent erosion and improve water retention. Also, the practice can potentially enhance the conservation of biodiversity (for example in soil microbial communities) .

### 2. Cropland management: nutrient management

203. **Mitigation potential**: The potential of this mitigation practice to sequester C and reduce $N_2O$ emissions under different climate zones is presented in table 10.

**Table 10. Mitigation potential through improved nutrient management**

| Climate zone | $CO_2$ (t $CO_2$ ha$^{-1}$yr$^{-1}$) | $N_2O$ (t $CO_2$ eq ha$^{-1}$ yr$^{-1}$) |
|---|---|---|
| Cool-dry and warm-dry | 0.26 (-0.22–0.73) | 0.07 (0.01–0.32) |
| Cool-moist and warm-moist | 0.55 ( 0.01–1.10) | 0.07 (0.01–0.32) |

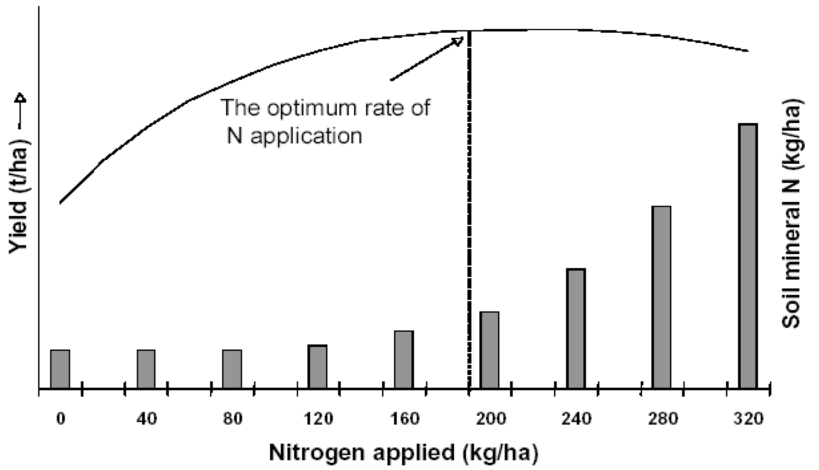
*Source*: IPCC. 2007b. *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmetal Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, New York, United States.
*Note*: Values in parentheses correspond to low and high mitigation potential. Positive values represent $CO_2$ uptake, which increases the soil carbon stock, or a reduction in emissions of $N_2O$.

204. **How to achieve**: Practices that improve N use efficiency include: adjusting application rates based on precise estimation of crop needs (e.g. precision farming); using slow- or controlled-release fertilizer forms or nitrification inhibitors (that slow the microbial processes leading to $N_2O$ formation); applying N when least susceptible to loss, often just prior to plant uptake (improved timing); placing the

N more precisely into the soil to make it more accessible to crop roots; or avoiding N applications in excess of immediate plant requirements (IPCC. 2007b). The adequate and timely addition of nutrients, when deficient, can also promote soil C gains (Alvarez, 2005).

205. This practice requires, for a given area or farming system, the establishment of a relationship between the rate of N application, crop yield and soil mineral N status. Figure 15 provides an example of such a relationship. A good fertilizer recommendation system ensures that the necessary quantities of essential crop nutrients are available only when required for uptake by the crop. Nutrients are only applied as mineral fertilizer when the supply of nutrients from all other sources is insufficient to meet crop requirements. As a result, the amount of excess nutrients in the soil is reduced to a minimum. The system also ensures that the soil is in a sufficiently fertile state to maximize the efficient use of nutrients already in the soil, or supplied from other sources such as organic manures. Maintaining an appropriate balance of other nutrients (P, K and S) is also necessary to maximize efficient plant N uptake and reduce losses to a minimum.

**Figure 15. Example of the relationship between the rate of nitrogen application, crop yield and soil mineral nitrogen status**




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

206. **Methodologies to estimate emissions**: The method for estimating change in C stocks in soils in cropland is provided in the 2006 IPCC Guidelines, volume 4, chapter 5. For $N_2O$ emissions, the generic methodologies adopted for managed soils, including indirect $N_2O$ emissions from additions of N to land due to deposition and leaching, are provided in chapter 11 of the 2006 IPCC Guidelines.

207. **Challenges**: The main challenge in this mitigation measure is how to encourage farmers and land managers to ensure that fertilizer recommendation guidelines are being followed, and how to teach them to make use of available guidance and other information sources. Another challenge would be for farmers and land managers to spend more resources in monitoring the level of N and in ensuring that the N is sufficient for the crop.

208. **Opportunities**: N applied through fertilizers, manure, biosolids, and other N sources is not always used efficiently by crops and the surplus N is usually emitted as $N_2O$ (Smith et al., 2007). Improving N use efficiency can reduce $N_2O$ emissions, indirectly reduce GHG emissions from N fertilizer manufacture (Schlesinger, 1999) and reduce expenses on fertilizers.

209. **Co-benefits/contribution to sustainable development**: This mitigation practice will improve soil, water and air quality as less N will be used as fertilizer to attain higher productivity. Less N fertilizer applied in soils would mean less N available for leaching and volatile losses.

3. Cropland management: tillage/residue management

210. **Mitigation potential**: The potential of this mitigation practice to sequester C and reduce $N_2O$ emissions under different climate zones is presented in table 11.

**Table 11. Potential mitigation through tillage and residue management**

| **Climate zone** | **$CO_2$ (t $CO_2$ $ha^{-1}$ $yr^{-1}$)** | **$N_2O$ (t $CO_2$ –eq $ha^{-1}$ $yr^{-1}$)** |
|---|---|---|
| Cool-dry | 0.15 (-0.48–0.77) | 0.02 (-0.04–0.09) |
| Cool-moist | 0.51 0.00–1.03) | 0.02 (-0.04–0.09) |
| Warm-dry | 0.33 (-0.73–1.39) | 0.02 (-0.04–0.09) |
| Warm-moist | 0.70 (-0.40–1.80) | 0.02 (-0.04–0.09) |

*Source*: IPCC. 2007b. *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmetal Panel on Climate Change.* Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
*Note*: Values in parentheses correspond to low and high mitigation potential. Positive values represent $CO_2$ uptake, which increases the soil carbon stock, or a reduction in emissions of $N_2O$.

211. **How to achieve**: This mitigation practice is achieved by allowing crops to grow with minimal or reduced tillage or without any tillage at all (no-till). These practices are being increasingly used across the world. Given that soil disturbance tends to stimulate soil C losses through enhanced decomposition and erosion, reduced- or no-till agriculture often (but not always) results in soil C gain. Reduced tillage or no-till practice may affect $N_2O$ emissions but the net effects are not well quantified and understood (IPCC. 2007b).

212. **Methodologies to estimate emissions**: The method for estimating change in C stocks in soils on cropland is provided in the 2006 IPCC Guidelines, volume 4, chapter 5. For $N_2O$ emissions, the generic methodologies adopted for managed soils, including indirect $N_2O$ emissions from additions of N to land due to deposition and leaching, are provided in chapter 11 of the 2006 IPCC Guidelines ($N_2O$ emissions from managed soils).

213. **Challenges**: Minimum tillage may increase resistant weed populations, soil compostation and disease problems (Davies et al., 2006) and therefore may increase reliance on chemical control. The use of chemicals for weed control is being minimized owing to its damaging effects on human health and the environment. Alternative weed control approaches include biological control by introducing pest predators, which also promote biodiversity.

214. **Opportunities**: No-tillage systems can reduce $CO_2$ emissions from energy use (Koga et al., 2006; Marland et al., 2003b). Systems that retain crop residues also tend to increase soil C because these residues are the precursors for organic soil matter, the main C store in soil. Avoiding the burning of residues (e.g. mechanizing sugarcane harvesting, eliminating the need for pre-harvest burning (Cerri et al., 2004) also prevents emissions of aerosols and GHGs generated from fire, although $CO_2$ emissions from fuel use may increase.

215. **Co-benefits/contribution to sustainable development**: Non-tillage (rather than ploughing) can be a useful way to maintain surface organic matter and preserve good soil structure. The resulting soil condition improves infiltration and retention of water, and reduces the risk of soil erosion and degradation. In addition to improving water and soil conservation, the adoption of this mitigation practice will increase productivity (food security) and support biodiversity and wildlife habitat.

4. Cropland management: water management (irrigation and drainage)

216. **Mitigation potential**: The potential of this practice to sequester C is 1.14 (-0.55–2.82) t $CO_2$ per ha per year in each climate zone.

217. **How to achieve**: Expanding the world's cropland area (where water reserves allow) or using better irrigation measures can enhance C storage in soils through enhanced yields and residue returns. Drainage of croplands in humid regions can promote productivity while suppressing $N_2O$ emissions by improving aeration. Some of the gains in water management (through irrigation and drainage) may be offset by $CO_2$ from energy used for irrigation or from $N_2O$ emissions from higher moisture and fertilizer N inputs (IPCC. 2007b).

218. **Methodologies to estimate emissions**: The method for estimating change in C stocks in soils in cropland is provided in the 2006 IPCC Guidelines, volume 4, Chapter 5.

219. **Challenges**: N lost through drainage may result in $N_2O$ emissions (Reay et al., 2003). There will also undoubtedly be social and environmental trade-offs to consider in semi-arid and sub-humid environments, particularly in relation to increased water abstraction for irrigation.

220. **Opportunities**: The opportunity that can be explored is to develop more efficient irrigation practices that use less fuel or energy.

221. **Co-benefits/contribution to sustainable development**: This mitigation practice is expected to promote productivity (food security) and the conservation of water resources and other biomes.

5. Rice cultivation

222. Rice is one of the most important crops and its cultivation is associated with the release of $CH_4$ and $N_2O$ emissions. Rice management practices can be considered as stand-alone mitigation options, although similar practices (also applicable to other crops) have already been discussed.

223. **Mitigation potential**: The management practices and their potential to reduce $CH_4$ emissions are shown in table 12.

224. **How to achieve**: Water management involves different strategies for flooding and draining fields such as pre-harvest drainage, early single or dual drainage, mid-season drainage, late dual drainage, and alternate flooding/drainage. Management of organic input includes the use of rice straw compost, mulching of rice straw, biogas manure and removal of rice stubbles from the fields. For mineral input management, the practice includes the use of phosphogypsum, ammonium sulphate and tablet urea. Direct seeding is the practice recommended for rice fields with reduced $CH_4$ emissions.

225. **Methodologies to estimate emissions**: The method for estimating $CH_4$ emissions from rice cultivation is provided in the 2006 IPCC Guidelines, volume 4, chapter 5.

**Table 12. Potential for the reduction of methane emissions in rice systems**

| Management practice | Continuous flooding, organic amendment | Mid-season drainage, organic amendment | Continuous flooding, no organic amendment |
|---|---|---|---|
| **Water regime** | Mid-season drainage (7–44 %) | | Mid-season drainage (15–80 %) |
| | Alternate flooding/drying (59–61 %) | Alternate flooding/drying (21–46 %) | Alternate flooding/drying (22 %) |
| | | Early/dual drainage (7–46%) | |
| **Organic amendments** | Compost (58–63 %) | Biogas residues (10–16 %) | |
| **Mineral amendments** | Phosphogypsum (27–37 %) | | Phosphogypsum (9–73 %) |
| | | | Ammonium sulphate (10–67 %) |
| | | | Table urea (10–39 %) |
| **Straw management** | | Fallow incorporation (11 %) | |
| | | Mulching (11 %) | |
| **Crop establishment** | Direct wet seeding (16–22 %) | | |

*Source*: 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.
*Note*: Values in parentheses are reduction effects for each mitigation practice or modified crop management.

226. **Challenges**: The main challenge is to ensure that the gains in reducing $CH_4$ emissions from rice fields are not offset by an increase in $N_2O$ emissions through the introduction of mineral N. Management of rice straw will be a challenge in implementing this practice. In most cases, rice straws are burned on site, instead of incorporating them back into the field to improve soil C content. However, burning of rice straw leads to higher emissions of non-$CO_2$ gases. Composting rice straw, instead of burning, would be a better management strategy, but this entails additional costs for farmers and land managers. Water management could also pose a challenge since this will require efficient irrigation and drainage systems.

227. **Opportunities**: Several studies have identified possible mitigation practices for reducing $CH_4$ from rice cultivation. The successful implementation of these practices will depend on identifying low-$CH_4$ emitting rice systems; developing a 'package' of mitigation technologies that could be more effective on a regional basis; ascertaining synergies with an increase in rice productivity; and accounting for $N_2O$ emissions.

228. **Co-benefits/contribution to sustainable development**: Rice management practices can promote productivity (food security) and conservation of other biomes (through composting of rice straw); and can enhance water quality through efficient use of water resources and mineral inputs.

6. Agroforestry

229. **Mitigation potential**: The potential of this mitigation practice to sequester C and reduce $N_2O$ emissions under different climate zones is shown in table 13.

**Table 13. Potential mitigation in agroforestry systems**

| Climate zone | $CO_2$ (t $CO_2$ ha$^{-1}$ yr$^{-1}$) | $N_2O$ (t $CO_2$–eq ha$^{-1}$ yr$^{-1}$) |
|---|---|---|
| Cool-dry | 0.15 (-0.48–0.77) | 0.02 (-0.04–0.09) |
| Cool-moist | 0.51 (0.00–1.03) | 0.02 (-0.04–0.09) |
| Warm-dry | 0.33 (-0.73–1.39) | 0.02 (-0.04–0.09) |
| Warm-moist | 0.70 (-0.40–1.80) | 0.02 (-0.04–0.09) |

*Source*: IPCC. 2007b. *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmetal Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, New York, United States.
*Note*: Values in parentheses correspond to low and high mitigation potential. Positive values represent carbon dioxide uptake, which increases the soil carbon stock, or a reduction in emissions of nitrous oxide.

230. **How to achieve**: Agroforestry is the production of livestock or food crops on land that also grows trees for timber, firewood or other tree products. This practice includes shelter belts and riparian zones/buffer strips with woody species. Soil C sequestration is increased by planting trees or woody species on cropland (IPCC. 2007b).

231. **Methodologies to estimate emissions**: The method for estimating changes in C stocks in above- and below-ground biomass are provided in the 2006 IPCC Guidelines, volume 4, chapter 5. For $N_2O$ emissions, the generic methodologies adopted for managed soils, including indirect $N_2O$ emissions from additions of N to land due to deposition and leaching, are provided in chapter 11 of the 2006 IPCC Guidelines.

232. **Challenges**: Depending on the species used, adopting this mitigation practice may increase soil C but the effects on $N_2O$ and $CH_4$ emissions are not well known and would need to be carefully studied. It is also necessary to ensure that this practice does not create the conditions that would lead to possible vectors, such as the tsetse fly, exposing livestock and humans to diseases such as trypanosomiasis.

233. **Opportunities**: This mitigation practice has the potential to contribute to the reduction of $CO_2$ from the use of fossil fuels.

234. **Co-benefits/contribution to sustainable development**: Adopting this mitigation practice will promote biodiversity and wildlife habitat. Planted and growing trees will improve the water holding capacity of the soil, though the trees may have a negative impact on water conservation since they might compete with crops for water. Thus agroforestry can contribute to climate change adaptation in some cases. Woody biomass (i.e. pruning) could be used as bioenergy (fuel wood) to replace fossil fuels that could have been used to generate energy or power for farm operations. Agroforestry can also contribute to poverty reduction.

### 7. Cropland management: set-aside, land-use change

235. **Mitigation potential**: The potential of this mitigation practice to sequester C and reduce $CH_4$ and $N_2O$ emissions under different climate zones is shown in table 14.

**Table 14. Potential mitigation through set asides and land-use change practices**

| Climate zone | $CO_2$ (t $CO_2$ ha$^{-1}$ yr$^{-1}$) | $CH_4$ (t $CO_2$ eq ha$^{-1}$ yr$^{-1}$) | $N_2O$ (t $CO_2$ eq ha$^{-1}$ yr$^{-1}$) |
|---|---|---|---|
| Cool-dry and warm-dry | 1.61 (- 0.07–3.30) | 0.02 (-0.00–0.02) | 2.30 (0.00–4.60) |
| Cool-moist and warm-moist | 3.04 (1.17–4.91) | 0.02 (-0.00–0.02) | 2.30 (0.00–4.60) |

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

*Note*: Values in parentheses correspond to low and high mitigation potential. Positive values represent carbon dioxide uptake, which increases the soil carbon stock, or a reduction in emissions of nitrous oxide and methane.

236. **How to achieve**: This mitigation practice is implemented by allowing or encouraging the reversion of cropland to another land cover, typically one similar to the native vegetation. The soil C is increased by changing the land use from cultivated land to permanent cropping (i.e. untilled land) which is either ungrazed or pasture, with a low stocking rate and zero or low N fertilizer inputs. The change can occur over the entire land area ('set-asides'), or in localized spots, such as grassed waterways, field margins or shelterbelts. Such land cover change or increase in vegetation (biomass stock) often leads to increases in soil C storage and reduction in direct $N_2O$ emissions through lower mineral N inputs (IPCC. 2007b).

237. As an example, converting arable cropland to grassland typically results in the accrual of soil C because of lower soil disturbance and reduced C removal in harvested products. Compared with cultivated lands, grasslands may also have reduced $N_2O$ emissions from lower N inputs, and higher rates of $CH_4$ oxidation, but recovery of oxidation may be slow (Paustian et al., 2004). In addition, converting drained croplands back to wetlands can result in rapid accumulation of soil C (removal of atmospheric $CO_2$), although this conversion may stimulate $CH_4$ emissions because waterlogging creates anaerobic conditions (Paustian et al., 2004). Planting trees can also reduce emissions since trees sequester $CO_2$ and store C in their above-ground and below-ground biomass.

238. **Methodologies to estimate emissions**: The method for estimating change in C stocks in soils in cropland is provided in the 2006 IPCC Guidelines, volume 4, chapter 5. Methodologies to estimate $CH_4$ emissions from wetlands (peatlands) are provided in chapter 7 of the 2006 IPCC Guidelines. For $N_2O$ emissions, the generic methodologies adopted for managed soils, including indirect $N_2O$ emissions from additions of N to land due to deposition and leaching, are provided in chapter 11 of the 2006 IPCC Guidelines.

239. **Challenges**: This practice is an extreme change in land use, which is unlikely to be adopted by farmers, in particular by subsistence farmers, whose livelihood depends on crop harvests. Thus a provision for suitable financial incentives must be explored if this mitigation practice is to be adopted. It may be particularly suited to areas where the converted land has conservation value. In addition, it is necessary to ensure that the issue of potential leakage is addressed.

240. **Opportunities**: This mitigation practice is applicable to all forms of arable farmland but is potentially most suited to marginal arable lands that were historically utilized as grazing land. Since land cover (or use) conversion comes at the cost of agricultural productivity, the practice is usually an option only on surplus agricultural land or on croplands of marginal productivity.

241. **Co-benefits/contribution to sustainable development**: Adopting this mitigation practice will promote trees and vegetation to grow which could result in improvements in soil, water and air quality. The practice is also expected to promote water and energy conservation; support biodiversity, wildlife habitat and the conservation of other biomes.

### 8. Grassland management: grazing, fertilization, fire control

242. **Mitigation potential**: The potential of this mitigation practice to sequester C and reduce $CH_4$ emissions under different climate zones is shown in table 15.

**Table 15. Potential mitigation through improved grazing, fertilization and fire control**

| Climate zone | $CO_2$ (t $CO_2$ ha$^{-1}$ yr$^{-1}$) | $CH_4$ (t $CO_2$ eq ha$^{-1}$ yr$^{-1}$) |
|---|---|---|
| Cool-dry | 0.11 (-0.55–0.77) | 0.02 (0.01 – 0.02) |
| Cool-moist | 0.81 (0.11–1.50) | – |
| Warm-dry | 0.11 (-0.55–0.77) | – |
| Warm-moist | 0.81 (0.11–1.50) | – |

*Source*: IPCC. 2007b. *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmetal Panel on Climate Change.* Cambridge University Press, Cambridge, United Kingdom and New York, New York, USA.
*Note*: Values in parentheses correspond to low and high mitigation potential. Positive values represent carbon dioxide uptake, which increases the soil carbon stock, or a reduction in emissions of nitrous oxide.

243. **How to achieve**: There is a range of practices that would improve pasture and animal production along with C sequestration through improvements in forage quality and the availability of forage for grazing animals, resulting in higher animal yields and reduced $CH_4$ emissions per unit of output. In particular:

(a) Grazing intensity: controlling grazing intensity by regulating stocking rate, enhancing rotational grazing and limiting grazing time by season over the year; most often, a C accrual on optimally grazed lands is greater than on ungrazed or overgrazed lands (IPCC. 2007b). However, effects are inconsistent because of the many types of grazing practices and the diversity of plant species, soils and climates involved (IPCC. 2007b). Where grassland is intensively grazed or overgrazed, soil carbon levels may decrease as the levels of residual vegetation carbon to be returned to the soil become limited;

(b) Pasture productivity: increasing pasture productivity (higher above-ground biomass density) by means of N fertilization, irrigation and other practices (Smith et al, 2007) or better management of natural resources (soils, water and plants). As in the case of croplands, C storage in grazing lands can be improved through a variety of measures that promote productivity (IPCC. 2007b);

(c) Nutrient management: practices that tailor nutrient additions to plant uptake can reduce $N_2O$ emissions (Dalal et al., 2003; Follett et al., 2001). Nutrients are applied (as mineral fertilizer) only when the supply of nutrients from other sources is insufficient to meet the crop requirements. Rotational grazing, resulting in more regular manure spread, is another way of improving nutrient cycling (IPCC. 2007b);

(d) Fire management: the practice is implemented by reducing the frequency or intensity of fires, reducing the fuel load by vegetation management, and burning at a time of year when less $CH_4$ and $N_2O$ are emitted (Korontzi et al., 2003). This practice is expected to increase tree and shrub cover that could result in a $CO_2$ sink in soil and biomass (Scholes and van der Merwe, 1996);

(e) Species introduction: this practice introduces grass species with higher productivity, or C allocation to deeper roots, which could result in increased soil C. An example of this practice is the establishment of deep-rooted grasses in savannahs, which has been reported to yield very high rates of C accrual (Fisher et al., 1994). Introduction of legumes into grazing lands also promotes soil C storage (Soussana et al., 2004) through enhanced productivity from the associated N inputs (IPCC. 2007b).

244. **Methodologies to estimate emissions**: The method for estimating changes in C stocks in grasslands is provided in the 2006 IPCC Guidelines volume 4, chapter 6. For $N_2O$ emissions, the generic

methodologies adopted for managed soils, including indirect $N_2O$ emissions from additions of N to land due to deposition and leaching, are provided in chapter 11 of the 2006 IPCC Guidelines.

245. **Challenges**: Grazing intensity has to be properly regulated to avoid overgrazing, soil degradation or desertification. The main barrier in assessing the impact of this cluster of practices on enteric $CH_4$ emissions in livestock production systems is the variability of the field trial results owing to their strong dependence on environmental conditions (climate, soil type, vegetation formation and water quality) and the fact that enteric emissions are not directly due to ruminant animals but to the methanogenic microbes present in the rumen (PGrRc, 2007). Economic incentives are needed to accelerate the adoption of these mitigation practices. As the results are site-dependent, owing to the incidence of environmental conditions, these practices need to be assessed comprehensively whenever they are implemented. Environmental impacts due to the introduction of plant species must be assessed.

246. In order to obtain a better understanding of the net benefits of improvements in pasture management, a complete GHG assessment has to be performed. Such an assessment would have to take into account emissions from higher nutrient application, irrigation practices and any other management practice that involve GHG emissions; reductions in $CH_4$ emissions due to improved animal performance or reduction in the stocking rate; and increasing C sequestration due to increased pasture.

247. **Opportunities**: There are opportunities to explore the best combination of pasture management practices (grazing intensity, nutrient management, introduction of new grass species and others) that will provide the highest benefits to grassland management while increasing soil C and reducing the emissions of non-$CO_2$ gases.

248. Opportunities are linked to natural grasslands in areas where rainfall is rather high, allowing a rapid regeneration of grasses. But increased emissions due to increased N application (from mineral fertilizers, animal manure and from a major proportion of legume forage species) has to be assessed in order to obtain a better understanding of the net GHG benefits of improving pasture management practices.

249. Improving pasture management practices is a low-tech mitigation option that can be readily adopted by farmers.

250. **Co-benefits/contribution to sustainable development**: Grazing land management can improve soil quality by increasing soil C; preventing desertification, avoiding overgrazing and promoting biodiversity and wildlife habitat; and enhancing aesthetic/amenity value of lands. Nutrient management may increase the productivity of grasslands, thus providing enough food for animals (food security). Fire management will increase the productivity of grasslands to serve as food for animals, while improving the quality of air and water. Other co-benefits would include the reduction of soil erosion and the enhancement of efforts to alleviate poverty.

### 9. Restoration of organic soils

251. **Mitigation potential**: The potential of this mitigation practice to sequester C and reduce $N_2O$ emissions under different climate zones is shown in table 16.

252. **How to achieve**: Restored organic soils are soils in wetlands which have been drained and perhaps converted to other uses in the past, but have recently been restored back to functioning wetland ecosystems by raising the water table to pre-drainage levels. This mitigation practice can be achieved by avoiding the drainage of organic or peaty soils that are known to contain high densities of C, or by re-establishing a high water table in the area (Freibauer et al., 2004). In addition, emissions from drained organic soils can be reduced to some extent by practices such as avoiding row crops and tubers, avoiding deep ploughing and maintaining a shallower water table (IPCC. 2007b).

**Table 16. Potential mitigation of organic soil restoration**

| Climate zone | $CO_2$ (t $CO_2$ $ha^{-1}$ $yr^{-1}$) | $CH_4$ (t $CO_2$ eq $ha^{-1}$ $yr^{-1}$) | $N_2O$ (t $CO_2$ eq $ha^{-1}$ $yr^{-1}$) |
|---|---|---|---|
| Cool-dry and cool-moist | 36.67 (3.67–69.67) | -3.32 (-0.05– -15.30) | 0.16 (0.05–0.28) |
| Warm-dry and warm-moist | 73.33 (7.33–139.33) | -3.32 (-0.05– -15.30) | 0.16 (0.05–0.28) |

*Source*: IPCC. 2007b. *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmetal Panel on Climate Change.* Cambridge University Press, Cambridge, United Kingdom and New York, New York, United States.
*Note*: Values in parentheses correspond to low and high mitigation potential. Positive values represent carbon dioxide uptake which increases the soil carbon stock, or a reduction in emissions of nitrous oxide and methane.

253. **Methodologies to estimate emissions**: The methods for estimating emissions of $CO_2$ and non-$CO_2$ gases in wetlands,which include peatlands and organic soils, are provided in the 2006 IPCC Guidelines, volume 4, chapter 7. However, the estimation of GHG emissions and removals from restored or constructed wetlands remains an area for further development.

254. **Challenges**: Most operational wetland restorations have occurred since 1990. The technical literature describes programmes or projects in some 15 countries in North America, Europe, Asia, and Australia and New Zealand, particularly in river deltas. This literature suggests that wetland ecosystems can be restored, but over variable periods of time and only up to a certain degree (it is unlikely that they can be returned to their original natural state). Currently, there is no compilation of the global area of wetland restoration and construction.

255. At the time of preparation of the 2006 IPCC Guidelines, studies published based on observational data were too recent and limited for default emission factors to be developed for any of the major GHGs: $CO_2$, $CH_4$ or $N_2O$. A better understanding of the biogeochemical fluxes within drainage basins is still needed to prevent double-counting of emissions from fertilizer application and waste treatment. Another challenge is related to maintaining a balance (or net benefit) between $N_2O$ reductions and $CH_4$ increases from restoration.

256. **Opportunities**: Since no methodology is provided to estimate GHG emissions or removals from restored peatlands, countries with extensive restored peatlands may consider developing or gathering the scientific information to support the development of GHG estimation methodologies.

257. **Co-benefits/contribution to sustainable development**: The primary purpose of restoring former wetlands is to reduce the run-off from agricultural fields and settlements, which causes eutrophication, algal blooms and hypoxic dead zones in lakes, estuaries, and enclosed bays and seas. Other important benefits include reducing flood damage, stabilizing shorelines and river deltas, retarding saltwater seepage, recharging aquifers, and improving wildlife, waterfowl and fish habitat. Restoration of organic soils is also expected to improve soil quality and aesthetic/amenity value, promote biodiversity and wildlife habitat, and support energy conservation.

### 10. Restoration of degraded lands

258. **Mitigation potential**: The potential of this mitigation practice to sequester C and reduce $CH_4$ emissions under different climate zones is presented in table 17.

259. **How to achieve**: Excessive disturbance, erosion, loss of organic matter, salinization acidification, or other processes that curtail productivity have contributed to degradation of agricultural lands (Batjes, 1999; Foley et al., 2005; Lal, 2001a, Lal, 2003, and Lal, 2004b). In this mitigation practice, the idea is to restore lost C through practices that reclaim productivity, including re-vegetation

(e.g. planting grasses); improving fertility through nutrient amendments; applying organic substrates such as manures, biosolids and composts; reducing tillage and retaining crop residues; and conserving water (Bruce et al., 1999; Lal, 2001b; Lal, 2004b; Olsson and Ardö, 2002; and Paustian et al., 2004) (cited in IPCC. 2007b).

**Table 17. Potential mitigation through degraded land restoration**

| Climate zone | $CO_2$ (t $CO_2$ ha$^{-1}$ yr$^{-1}$) | $CH_4$ (t $CO_2$ eq ha$^{-1}$ yr$^{-1}$) |
|---|---|---|
| Cool-dry | 3.45 (-0.37–7.26) | 0.08 (0.04–0.14) |
| Cool-moist | 3.45 (-0.37–7.26) | 1.00 (0.69–1.25) |
| Warm-dry | 3.45 (-0.37–7.26) | – |
| Warm-moist | 3.45 (-0.37–7.26) | – |

*Source*: IPCC. 2007b. *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmetal Panel on Climate Change.* Cambridge University Press, Cambridge, United Kingdom and New York, New York, United States.
*Note*: Values in parentheses correspond to low and high mitigation potential. Positive values represent carbon dioxide uptake, which increases the soil carbon stock, or a reduction in emissions of methane.

260. **Methodologies to estimate emissions**: The method to estimate change in C stocks in soils in degraded land is provided in the 2006 IPCC Guidelines, volume 4, chapter 9. For $CH_4$ emissions, the generic methodologies in chapter 2 of the 2006 IPCC Guidelines provide some guiding principles on how to estimate emissions from degraded soils.

261. **Challenges**: In cases where these practices involve higher N inputs to the soil, the benefits of C sequestration may be partly offset by higher $N_2O$ emissions and this needs to be considered.

262. **Opportunities**: The long-term benefits of this practice should be explored in terms of the increased soil productivity, the effects on water quantity and quality, the use of biomass as a source of energy, and the conservation of or increase in biodiversity.

263. **Co-benefits/contribution to sustainable development**: This mitigation practice will increase soil productivity, thus increasing food security; improve soil and water quality and aesthetic/amenity value; and support biodiversity, wildlife habitat and the conservation of other biomes.

### 11. Bioenergy (soils only)

264. **Mitigation potential**: The potential of this mitigation practice to sequester C and reduce $N_2O$ emissions under different climate zones is presented in table 18.

**Table 18. Potential mitigation in soils for bioenergy production**

| Climate zone | $CO_2$ (t $CO_2$ ha$^{-1}$ yr$^{-1}$) | $N_2O$ (t $CO_2$ eq ha$^{-1}$ yr$^{-1}$) |
|---|---|---|
| Cool-dry | 0.15 (-0.48 – 0.77) | 0.02 (-0.04 – 0.09) |
| Cool-moist | 0.51 (0.00 – 1.03) | 0.02 (-0.04 – 0.09) |
| Warm-dry | 0.33 (-0.73 – 1.39) | 0.02 (-0.04 – 0.09) |
| Warm-moist | 0.70 (-0.40 – 1.80) | 0.02 (-0.04 – 0.09) |

*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.
*Note*: Values in parentheses correspond to low and high mitigation potential. Positive values represent carbon dioxide uptake, which increases the soil carbon stock, or a reduction in emissions of nitrous oxide.

265. **How to achieve**: This mitigation practice involves the use of agricultural crops and residues that can be burned directly but can also be processed further to generate liquid fuels such as ethanol or diesel. Such fuels release $CO_2$ when burned, but this $CO_2$ is of recent atmospheric origin (via photosynthetic C uptake) and displaces $CO_2$ which otherwise would have come from fossil C.

266. **Methodologies to estimate emissions**: The method to estimate emissions from fuel combustion in agriculture and forestry is provided in the 2006 IPCC Guidelines volume 2, chapter 2.

267. **Challenges**: The competition for other land uses and the environmental impacts need to be considered when planning to use energy crops. In addition, the net benefit for the atmosphere will depend on the type of energy used (e.g. fossil fuels vs. renewable energy) in growing and processing the bioenergy feedstock (Spatari et al., 2005).

268. **Opportunities**: The interactions of an expanding bioenergy sector with other land uses, and impacts on agroecosystem services such as food production, biodiversity, soil and nature conservation, and C sequestration have not yet been studied adequately, although bottom-up approaches (Smeets et al., 2007) and integrated assessment modelling (Hoogwijk, 2004; Hoogwijk et al., 2005) offer opportunities to improve understanding.

269. Major transitions are required to exploit the large potential for bioenergy. Improving agricultural efficiency in developing countries is a key factor. It is still uncertain as to what extent, and how fast, such transitions could be realized in different regions. Under less favourable conditions, the regional bioenergy potential(s) could be quite low. Technological developments in converting biomass to energy, as well as long-distance biomass supply chains (e.g. those involving intercontinental transport of biomass-derived energy carriers) can dramatically improve the competitiveness and efficiency of bioenergy (Faaij, 2006; Hamelinck et al., 2004).

270. **Co-benefits/contribution to sustainable development**: Adopting this mitigation practice will promote energy conservation.

### B. Future mitigation practices

271. Table 31 in the annex presents a few future practices in agriculture (crops and soils) that have the potential to increase soil C or reduce GHG emissions. These practices include reduced or zero tillage; use of nitrification inhibitors; improvement in application and timing of mineral N fertilizers ; use of plants with improved N use efficiency; and production of natural nitrification inhibitors by plants.

272. The GHG balance of reduced tillage or no-till systems would need to be quantified in field experiments to check whether the increase in soil C storage outweighs the $N_2O$ emissions. As regards the use of nitrification inhibitors, field-based experiments would need be conducted to quantify the potential of nitrification inhibitors to mitigate $N_2O$ emissions from mineral fertilizer N and manure application to land and grazed pastures, and to determine the associated potential benefits to crop N use efficiency and water quality improvements. There is a need to develop improved mineral fertilizer N application timing policies that explicitly aim to reduce $N_2O$ emissions.

## VIII. Case studies for crops and soils

273. In the previous chapter, it was noted that there is insufficient information in several areas of abatement or sequestration of agricultural emissions. In this chapter, two new analyses are presented which develop these themes further. These analyses are based on publicly available information.

### A. Reducing emissions associated with conversion of land to cropping

274. This case study focuses on the impact of agricultural intensification in land areas that are used to produce cereal crops. An analysis of intensification of cereal crop production is presented to indicate the potential for emission reductions associated with intensification.

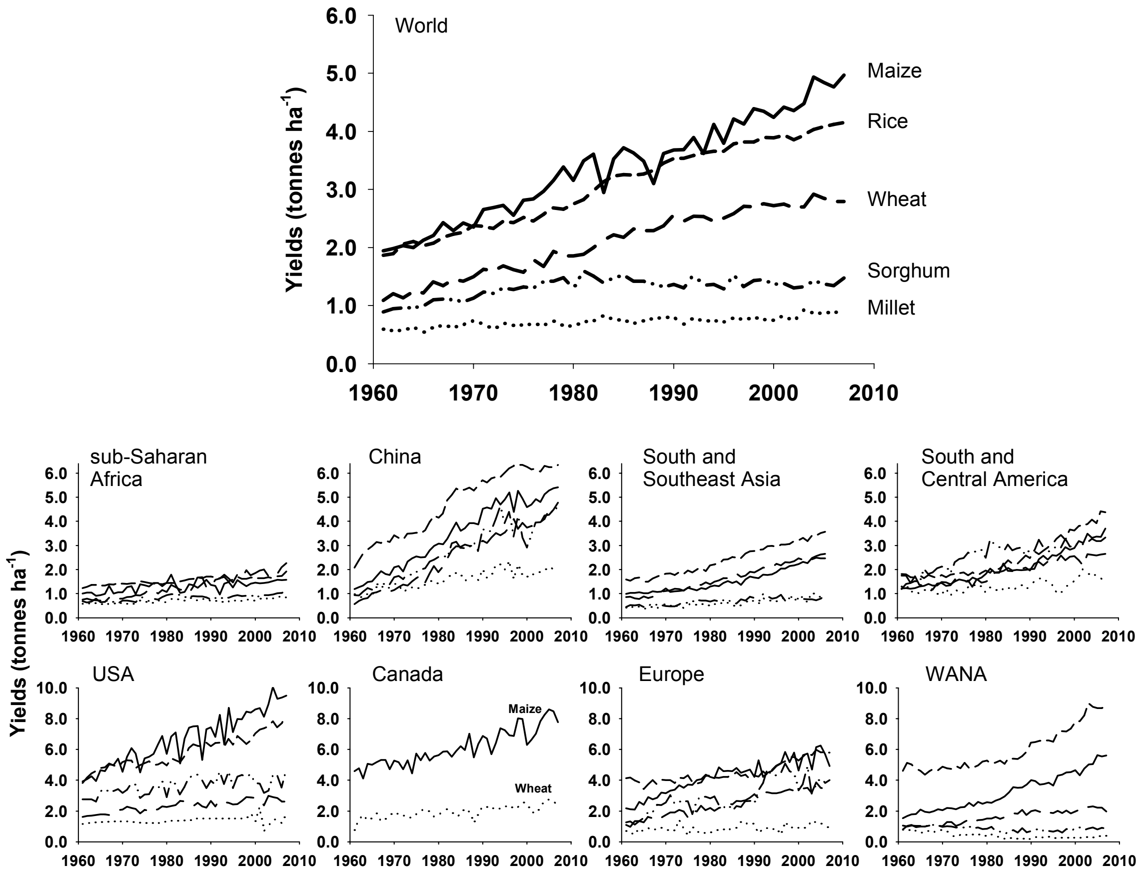
275. Cereal crops have represented 45–60 per cent of the world's croplands over the past 40 years (FAOSTAT, 2008). Agricultural intensification in many developing countries was the result of a large international effort – the Green Revolution – led by several international crop research centres that belong to the Consultative Group for International Agricultural Research (CGIAR). The CGIAR currently comprises 15 international centres working on agriculture and natural resource management matters.

276. In developed countries, large investments in agricultural research led to the intensification of production systems. Thus, in 1965 the world produced over 900 million t of cereals to feed 3.3 billion people on about 670 million ha; in 2005, over 2.3 billion t of cereals were produced for 6.5 billion people on 690 million ha. So while there has been a more than three-fold increase in cereal production, the harvested area for these crops has increased by less than 2 per cent.

277. According to FAOSTAT (2008) five cereals account for over 90 per cent of the global cereal production: maize, millet, sorghum, rice and wheat. The impact of intensification was evaluated by constructing two simple, regionally disaggregated scenarios of the land required to meet production levels in 2006. Two yield values for these scenarios were used: average yield rates for 1964–1966, before significant intensification, and average yield rates for 2004–2006, after intensification. From these yield rates, the additional land that would have been required to achieve the production levels of the yields in the 1960s and from 2000 onwards was calculated. This represents the land-use savings achieved through intensification.

278. With the exception of sub-Saharan Africa, yields of most cereal crops have more than doubled since the early 1960s (see figure 16). Maize, rice and wheat are the most widely cultivated cereals; millet and sorghum represent only about 2–3 per cent of worldwide cereal production (see table 20). However, these grains are more important in African agriculture, making up 15–20 per cent of the production, and are included here for that reason. Other regional differences in grain production include high rice production in Asia and higher wheat production at high latitudes.

## Figure 16. Yields of cereal crops, 1961–2006




*Source*: Food and Agriculture Organization of the United Nations. FAOSTAT database <http://faostat.fao.org>.
*Note*: Line formats in all graphs follow those of the global analysis, with the exception of Canada, which only produces maize and wheat.

### Table 19. Production rates for five cereals in case study regions and countries, 2004–2006 (*millions of tonnes*)

| | Maize | Millet | Rice | Sorghum | Wheat | Total |
|---|---|---|---|---|---|---|
| Sub-Saharan Africa | 42 | 15 | 14 | 19 | 5 | 96 |
| West Asia North Africa | 12 | 1 | 7 | 6 | 50 | 76 |
| South and Central America | 90 | – | 25 | 12 | 25 | 151 |
| South and Southeast Asia | 49 | 11 | 364 | 7 | 111 | 543 |
| China | 139 | 2 | 182 | 2 | 98 | 423 |
| United States | 283 | – | 10 | 10 | 55 | 358 |
| Canada | 9 | – | – | – | 25 | 34 |
| Europe | 87 | 1 | 3 | 1 | 207 | 298 |
| **World** | **714** | **31** | **628** | **59** | **619** | **2 051** |

*Source*: Food and Agriculture Organization of the United Nations. FAOSTAT database <http://faostat.fao.org>.

279. Table 20 summarizes the harvested land area for the cereals in the nine case studies. In absolute terms, cropland for cereal production is expanding most rapidly in South and Southeast Asia and in sub-Saharan Africa. Over the past 40 years, harvested areas have expanded by over 300,000 km$^2$. On a

percentage basis, expansion is greatest in sub-Saharan Africa ( about 70 per cent). This is due in part to structural reforms in the agriculture sector in the past 20 years, which have focused on resolving marketing problems to the detriment of addressing production constraints. As input markets have crumbled across the continent, African farmers have responded to growing local demand by expanding agricultural lands rather than intensifying production on lands already under cultivation (Diabré, 1996).

280. At the same time, land devoted to cereals is decreasing in the developed world, particularly in Europe, where harvested areas have decreased by over 440,000 km2 or by 37 per cent. Canada has seen a small decrease in land area devoted to wheat and a small increase in area devoted to maize. In the United States, total area has remained stable, but there has been a shift to greater production areas for maize and rice and decreases in other cereals.

281. The other trend that can be observed is a large shift of land away from millet and sorghum. These grains still account for 50 per cent of the harvested area in sub-Saharan Africa, but elsewhere the area devoted to these cereals is declining. For example, in the 1960s 15 per cent of the harvested area in China was devoted to millet and sorghum. Today, the area is just a bit more than 1 per cent. Likewise areas devoted to these crops are decreasing in other areas of South and Southeast Asia, while such areas are expanding in countries in West Asia and North Africa.

**Table 20. Area planted to growing cereals, 1964–1966 and 2004–2006**
*(megahectares)*

| | **Maize** | **Millet** | **Rice** | **Sorghum** | **Wheat** | **Total** |
|---|---|---|---|---|---|---|
| | | | **1964–1966** | | | |
| Sub-Saharan Africa | 15.4 | 11.4 | 2.8 | 12.2 | 2.5 | 44.3 |
| West Asia and North Africa | 1.8 | 0.8 | 0.5 | 2.9 | 16.4 | 22.4 |
| South and Central America | 23.5 | 0.1 | 5.6 | 1.7 | 8.6 | 39.5 |
| South and Southeast Asia | 12.8 | 20.3 | 79.1 | 18.5 | 25.6 | 156.3 |
| China | 16.0 | 6.9 | 30.7 | 6.3 | 24.7 | 84.6 |
| United States | 22.6 | 0.1 | 0.7 | 26.2 | 20.1 | 69.8 |
| Canada | 0.3 | – | – | – | 11.8 | 12.1 |
| Europe | 14.9 | 3.4 | 0.6 | 0.2 | 98.0 | 117.1 |
| **World** | 108.5 | 43.4 | 125.2 | 47.3 | 216.4 | 540.8 |
| | | | **2004–2006** | | | |
| Sub-Saharan Africa | 27.0 | 18.2 | 8.2 | 19.1 | 2.8 | 75.3 |
| West Asia North Africa | 2.2 | 2.1 | 0.8 | 6.4 | 22.4 | 34.0 |
| South and Central America | 26.8 | 0.0 | 6.0 | 3.6 | 9.5 | 46.0 |
| South and Southeast Asia | 18.6 | 12.9 | 104.0 | 9.4 | 45.0 | 189.9 |
| China | 26.3 | 0.9 | 29.1 | 0.6 | 22.6 | 79.4 |
| United States | 29.6 | 17.8 | 1.3 | 20.3 | 19.8 | 70.8 |
| Canada | 1.1 | – | – | – | 9.5 | 10.6 |
| Europe | 14.4 | 0.5 | 0.6 | 0.2 | 57.5 | 73.0 |
| **World** | 147.3 | 35.3 | 153.9 | 42.5 | 217.2 | 596.2 |

*Source*: Food and Agriculture Organization of the United Nations. FAOSTAT database <http://faostat.fao.org>

282. Combining the yield data from 1964–1966 with average production data from 2004–2006, an estimate of the land area was produced that would have been required to meet production needs in the 2000's for each crop (see table 21). Using this estimate, it is possible to calculate the total land that would have been required to meet 2000's production levels at 1960s yields (see table 21).

**Table 21. Areas that would have been required to meet 2000's production levels at 1960s yields**
(*megahectares*)

| | Maize | Millet | Rice | Sorghum | Wheat |
|---|---|---|---|---|---|
| Sub-Saharan Africa | 44.4 | 27.4 | 10.4 | 27.2 | 7.4 |
| West Asia North Africa | 6.2 | 1.1 | 1.6 | 5.6 | 51.5 |
| South and Central America | 70.2 | 0 | 14.7 | 6.9 | 17.0 |
| South and Southeast Asia | 47.1 | 28.1 | 235.0 | 15.0 | 135.3 |
| China | 88.3 | 1.7 | 61.2 | 2.0 | 61.5 |
| United States | 64.4 | 0.2 | 2.1 | 3.1 | 31.3 |
| Canada | 1.8 | – | – | – | 15.9 |
| Europe | 32.9 | 1.3 | 0.9 | 0.4 | 147.5 |
| **World** | **338.5** | **51.8** | **303.1** | **57.6** | **480.6** |

*Source*: Adapted from the Food and Agriculture Organization of the United Nations. FAOSTAT database <http://faostat.fao.org>.

283. Globally, the area devoted to cereal crops would have had to double, compared with the amount of land under cultivation during 2004–2006, to meet production needs. China would have required an area 2.7 times larger than it cultivates today, whereas South and Central America and South and Southeast Asia would have required about 2.4 times the amount of land. In Africa, where intensification was lowest, yields have increased only slightly and farmers have responded largely by increasing the area cultivated (Kandji et al., 2006a; Kandji et al., 2006b; and Kandji and Verchot, 2007). Yet even in this region, 50 per cent more land would have been required to meet 2000's production levels in cereals.

284. This analysis is not intended to assess the spatial distribution of the potential land-use change that would have been required to meet current production levels. Also, no assessment is made of the possible impacts of using marginal agricultural land with potentially lower than average yields. However, given that productive land is generally favoured for cropping, it is likely that movement onto marginal land would have required an even greater land area to help meet production demands. Thus the estimates in table 22 can be considered as conservative.

**Table 22. Total areas for various countries and regions that would have been required to meet current production levels at 1960s yields compared to present agricultural areas**
(*megahectares*)

| | Area needed without intensification | Actual area planted mid 2000's | Area saved |
|---|---|---|---|
| Sub-Saharan Africa | 116.9 | 75.32 | 41.60 |
| West Asia and North Africa | 66.0 | 33.99 | 32.02 |
| South and Central America | 108.8 | 46.01 | 62.78 |
| South and Southeast Asia | 460.5 | 189.88 | 270.66 |
| China | 214.7 | 79.40 | 135.26 |
| United States | 101.1 | 70.79 | 30.27 |
| Canada | 17.7 | 10.56 | 7.09 |
| Europe | 183.0 | 73.04 | 110.01 |
| **World** | **1 231.6** | **596.15** | **635.42** |

*Source*: Adapted from the Food and Agriculture Organization of the United Nations. FAOSTAT database <http://faostat.fao.org>

285. Modelling exercises often give very different results, depending upon the assumptions used. Decampos et al. (2006) indicated that the regional land use change emissions based on country-level data, the forestry resources assessment carried out by the FAO, are highly dependent on the biome classification by country. Houghton (2005) looked at several assessments that used average biomass estimates to assess fluxes. These estimates ignore the possibility that deforestation occurs in forests with biomass that is significantly different from the average. The two sources of uncertainty – land area of a particular biome converted and the original biomass of the land that is deforested – lead to high levels of variation between different estimates of the land-use change flux. Thus, for this exercise, no attempt has been made to assign a C value to the increased land-use change that would have been used to meet the need for additional land requirements.

286. Nevertheless, to put this into perspective, between 2000 and 2005 the average annual deforestation rate was around 8 M ha. Land conversion would have added, on average an additional 16 M ha per year over the 40-year span, a significant portion of which would most likely have come from forest land. Thus continued investment in agricultural intensification is needed to ensure that as populations grow, more land is not converted to meet growing food needs.

## B. Carbon sequestration in grasslands and agroforestry plantations

287. The IPCC Special Report (2000) presented an illustration of the potential of C sequestration to contribute to climate change mitigation. What is presented in this section is an expansion of the IPCC Special Report scenario, which will illustrate the potential for C sequestration in the agriculture sector and the costs of achieving that sequestration. The results of this analysis will only be semi-quantitative, but it is reasonable to expect them to be indicative of the order of magnitude of the potentials and costs.

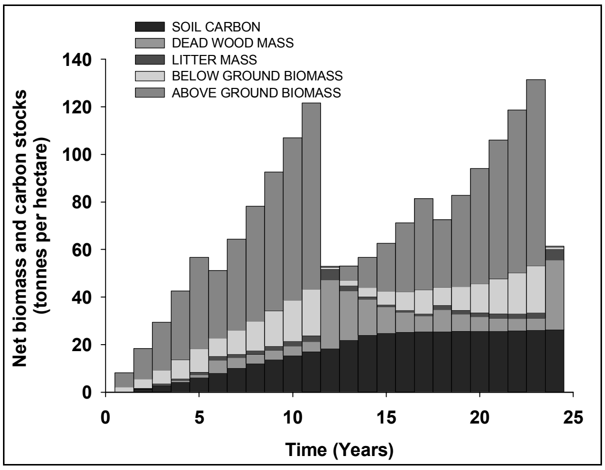
288. The IPCC scenario suggested that it would be possible, with considerable international effort, to place 10 per cent of the land available for improved pasture management under such management by 2010, and as much as 20 per cent under improved management by 2040. Likewise in the case of agroforestry, the report suggested that 20 per cent of the land available could be under this land management practice by 2010 and 40 per cent by 2040. At present, land availability levels are almost the same as those in 2000 and it is unlikely that the IPCC scenario projections for 2010 will be achieved.

289. For this analysis, an example of a moderately intensive agroforestry system is considered, which has been modelled using the ENCOFOR decision support carbon model (Emmer and Bird, 2007; see figure 17). The system produces timber, with some food or cash crops grown in the understory. Examples of this system are the rotational woodlots of Tanzania, the pine-coffee-banana systems of central Java, and the Eucalyptus and Poplar based agroforestry systems of the Indo-Gangetic Plain (Bekele-Tesemma, 2007).

290. In this system, the trees are harvested after 12 years, and regenerated. The ENCOFOR model suggests that the average annual accumulation in this example over 30 years is 1.26 t C per ha, and over 60 years this figure drops to 0.52 t per ha. The IPCC Special Report suggested that the average C accumulation rate in an agroforestry system was about 3.1 t per ha for a 30- to 50-year time horizon. These values are appropriate for a multi-strata system kept in place over a long period of time, such as the home garden systems of Africa or the jungle rubber agroforestry systems of Indonesia.

291. These two examples are used because they provide useful limits to the calculations presented here. One case deals with a system that is regularly harvested and therefore has lower annual accumulation rates because the above-ground biomass is regularly brought back to zero. The other case deals with a permanent tree-based farming system.

**Figure 17. Projected carbon accumulation in a multi-strata agroforestry system**




292. C sequestration potential can be calculated by taking the time frame proposed in the IPCC Special Report, taking the projections of area of land adopting the improved practices, and using both the IPCC and ENCOFOR projections for C accumulation rates, and the IPCC projection for grassland management. Table 23 presents the scenarios for agroforestry and grassland management. If we take the sum of the annual accumulation rates over the next 30 years, the result suggests that the total potential sequestration is of the order of 12–19 Gt C, or 45–70 Gt CO2 eq. This does not account for the C sequestered in wood products harvested from agroforestry plantations.

**Table 23. Estimated carbon sequestration in agricultural lands**

| | | | Permanent agroforestry (IPCC) | | Rotational agroforestry (ENCOFOR) | |
|---|---|---|---|---|---|---|
| Time (years) | Land area available (M ha) | Adoption/conversion of area (%) | Rate of C gain (t C ha $^{-1}$ y $^{-1}$) | Carbon (Mt y) | Rate of C gain (t C ha $^{-1}$ y $^{-1}$) | Carbon (Mt y) |
| | | | **Agroforestry** | | | |
| 10 | 630 | 20 | 3.1 | 391 | 1.26 | 159 |
| 15 | | 23 | | 456 | | 186 |
| 20 | | 27 | | 521 | | 212 |
| 25 | | 30 | | 586 | | 239 |
| 30 | | 33 | | 651 | | 265 |
| | | | **Grassland management** | | | |
| 10 | 3400 | 10 | 0.7 | 238 | | |
| 15 | | 12 | | 278 | | |
| 20 | | 13 | | 317 | | |
| 25 | | 15 | | 357 | | |
| 30 | | 17 | | 397 | | |

*Source:* Intergovernmental Panel on Climate Change (IPCC). 2000. *IPCC Special Report on Land Use, Land-Use Change and Forestry*. Cambridge: Cambridge University Press; and modelling using the Encofor tool.
*Note*: Two scenarios are presented for agroforestry, one based on Watson R, Noble IR, Bolin B, Ravindranath NH, Verardo DJ and Dokken DJ. (eds). 2000. *Land use, Land-use Change, and Forestry: A Special Report.* Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press. Cambridge, United Kingdom, and one based on the projections of the ENCOFOR Carbon Model, Emmer, I and N. Bird. 2007. *ENCOFOR Carbon Accounting and Project Design Manual*.
<http://www.joanneum.at/encofor/tools/tool_demonstration/Carbon_accounting_Module_PIN.html>. The time period for the analysis is 30 years.

293. To evaluate the investments required to achieve these levels of C sequestration, the agroforestry example developed above is considered. Costs of tree-planting projects include those associated with plantation establishment, maintenance costs such as pruning, and measurement and monitoring of the C sequestered. In many cases, farmer education is required to teach farmers about new agroforestry systems. To calculate these costs, the ENCOFOR financial analysis tool was used. Values are in 2005 United States dollars. Establishment costs include the purchase of seedlings, labour for site preparation and planting, and costs of protection (fencing, guarding, etc.). The cost of establishing these agroforestry plantations is about USD 780 for the two rotations of a one-hectare plantation of 1,000 trees. Operating costs include weeding, thinning and pruning the trees, which come to USD 440 per ha. Additional costs of preparing documentation for C crediting under the different types of systems that currently exist come to USD 60 per ha and the costs for monitoring and verifying are USD 190 per ha. Thus the total cost in this scenario is USD 1,470 per ha.

294. From the example above, an agroforestry plantation contains an average of 80 t of biomass over its lifetime or 40 t of C per ha in five C pools (above-ground biomass, below-ground biomass, deadwood, litter and soil C). The costs of establishment and maintenance of these plantations comes to USD 36.75 per tonne of C, or USD 10.02 per tonne of $CO_2$ eq.

295. The example given here has a 22 per cent internal rate of return. Agroforestry systems vary considerably across regions and have varying income generation potential. This means that the costs of expanding the adoption of agroforestry do not have to be fully borne by external investors. Costs can be shared with rural farmers who will benefit from these profitable systems. In most cases, agroforestry systems are more profitable than subsistence agriculture.

296. The idea of additionality in financing C sequestration is already embodied in the Convention and its Kyoto Protocol. Additionality is the criteria for C offset projects to determine offsets that occur in addition to business as usual. Additionality is determined by analysing barriers. Many barriers to adoption of these systems exist, and prevent these systems from contributing more fully to rural development, including:

(a) Delayed returns on investments: In most cases it takes three to five years to recoup initial investments in agroforestry systems. This is prohibitively long for small-holder, subsistence farmers. Alternative and shorter-term income sources are required to bridge the gap between planting and income generation;

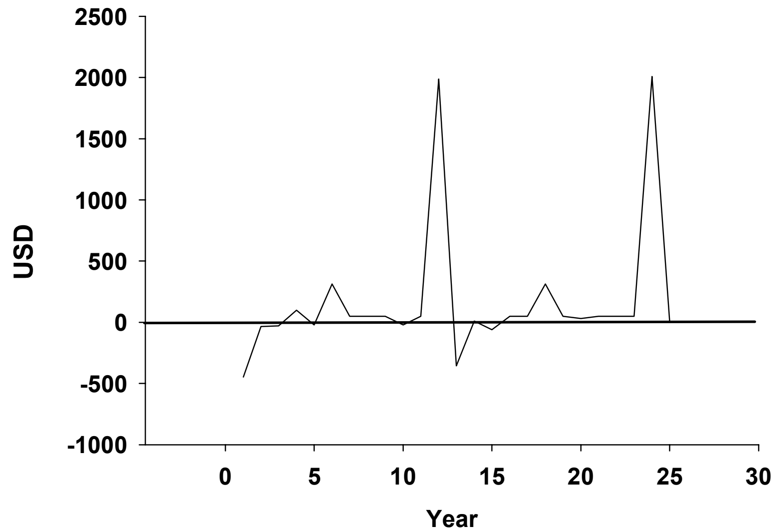
(b) Lack of knowledge: In many instances farmers lack knowledge about how to take full advantage of agroforestry systems and about the potential for increased income generation from such systems. Information on successful rural extension systems often does not exist and therefore cannot be passed on to farmers;

(c) Labour shortages: Agroforestry systems are generally more labour intensive than cropping systems. Farming families in rural areas in the developing world often have labour shortages during rainy seasons and therefore are not capable of taking full advantage of these periods. In many areas, men and women have left to find employment in cities and send remittances back to their families in the villages. Funding to purchase additional labour or lure family members back from the cities could help overcome this barrier.

297. Investments to facilitate wider adoption of higher C and higher profit production systems need to target removing these or other barriers that exist in rural areas. In the example above, one of the most important barriers preventing resource-poor farmers from engaging in this type of project is financial. Figure 18 shows that the cash flow for this type of plantation is negative for the first three years of the project. This is fairly common in agroforestry projects. A second barrier is lack of knowledge about agroforestry systems. Thus, despite the favourable internal rate of return, resource-poor farmers cannot

convert to this type of production system because of the financial barriers early in the conversion phase to a new production system and because of the knowledge barrier.

**Figure 18. Cash flow over two rotations of a moderately intensive agroforestry plantation in the tropics**
(*values taken at 2005 United States dollars*)




298. If additional investments were to be made to overcome these barriers, wider adoption of agroforestry could occur. In this case, investments of USD 640 per ha would be required and the cost of sequestering the C would be only USD 16 per tonne of C or USD 4.36 per t $CO_2$ eq. In the case of permanent agroforestry, assuming similar establishment and operating costs, the cost per tonne decreases to USD 4.32 because of the higher productivity of the system. Assuming similar costs to overcome barriers for these types of plantation, the cost of removing the barriers would be only USD 1.77 per tonne. Finally, to put this in a global perspective, the technical potential C sequestration of this scenario is 30.8 Gt $CO_2$ eq for a total cost of USD 134.4 billion. The actual potential suggested by the IPCC scenario is given in table 24.

**Table 24. Calculations of actual sequestration and costs for agroforestry using the IPCC scenario for adoption/conversion**

| | | Sequestration potential | | Implementation costs | |
|---|---|---|---|---|---|
| **Time (years)** | **Adoption/ conversion of area** | **Permanent agroforestry (Mt $CO_2$ eq yr)** | **Rotational agroforestry (Mt $CO_2$ eq yr)** | **Full (USD millions )** | **Barriers only (USD millions)** |
| 10 | 20 | 1 434 | 583 | 5 843 | 2 544 |
| 15 | 23 | 1 672 | 682 | 6 836 | 2 976 |
| 20 | 27 | 1 910 | 777 | 7 791 | 3 392 |
| 25 | 30 | 2 149 | 876 | 8 783 | 3 824 |
| 30 | 33 | 2 387 | 972 | 9 739 | 4 240 |

*Note*: Costs are calculated using total costs per hectare and the values suggested for investments aimed at removing barriers only.

299. Greater consideration of these land-use mitigation options is warranted, as these types of activity offer multiple benefits. If well designed, agroforestry, grassland management, land rehabilitation and

wetland rehabilitation projects can contribute to consideration of biodiversity conservation, watershed protection, reduction of desertification, sustainable land management and poverty reduction.

# IX. Policies and measures

## A. General

300. The adoption of any policy or measure that would lead to a reduction in GHG emissions from agriculture would need to take into account that:

(a) According to current projections, human population will continue to increase, reaching 8 billion by 2030, and will eventually stabilize to around 9–9.5 billion in the second part of this century (Lupien and Menza, 2008);

(b) Increases in human population would translate into equivalent increases in the demand for food, particularly for animal products. It is anticipated that developing countries would account for the majority of this new demand, as a consequence of economic growth and changes in lifestyle;

(c) Three quarters of agriculture emissions are in developing regions;

(d) Continued pressure for land-use change, mainly in developing countries, resulting in the conversion of forestlands to agricultural lands, would lead to C losses due to deforestation;

(e) Non-climate policies implemented by countries can affect the levels of GHG emissions from agriculture;

(f) Continued pressure on agricultural land for the production of biofuel crops;

(g) Mitigation efforts in agriculture can contribute towards sustainable development, food security and poverty alleviation efforts.

301. In order to ensure maximum efficiency of mitigation actions in agriculture, it would be appropriate to consider a systemic approach taking into account all aspects of agricultural systems (as well as the interactions between them) including co-benefits (e.g. forage improvements to increase animal productivity could result in reductions of enteric $CH_4$ emissions) and trade-offs (e.g. increasing fertilizer to increase productivity and soil carbon storage may increase emissions of $N_2O$ and $CH_4$). Such co-benefits and trade-offs would play an important role in the decision-making process regarding the selection of appropriate policies and measures at the national or regional level.

## B. Policies for reducing emissions from agriculture

302. As in other economic sectors, in agriculture mitigation efforts can be adopted: in the context of a multilateral international agreement; as part of a national strategy; as voluntary initiatives by the private sector. These options are not mutually exclusive and can be combined to achieve maximum benefit.

303. The effectiveness of international agreements (such as climate change agreements, free trade agreements and regional agreements) relies on the ratification of the agreed instruments by the participating governments. However, the success of these instruments depends on rigorous implementation at the national level. For this to happen, governments need to design national plans that take into account criteria such as: environmental effectiveness; cost-effectiveness; distributional considerations; institutional feasibility; as well as effects on competitiveness and administrative costs (IPCC. 2007a).

304. The main policy instruments at the disposal of national governments are: regulatory measures and standards; taxes and charges; tradable permits; voluntary agreements; information campaigns; financial incentives (subsidies and tax credits); and support for research and development and technology deployment. Such instruments may also be implemented in the absence of an international agreement.

305. Regulatory approaches can force farmers to modify their practices against their cultural background. In the absence of any incentives, however, it is likely that such an approach could lead to strong reactions from the farming community. Furthermore, compulsory regulation or standards create the complementary need to invest in building the capacity to measure reductions in order to comply with the regulated commitments and standards.

306. Voluntary agreements, although they could be considered as part of a package of measures at the national level, are usually seen as alternatives to regulation imposed by the government. Voluntary agreements can be established for the private sector (including industry and corporations), local and regional authorities and non-governmental organizations. Although voluntary agreements could increase the participation of stakeholders, their voluntary nature does not (in many cases) guarantee their environmental effectiveness.

307. For the selection of appropriate mitigation policies in agriculture and their effective implementation, the four key areas of concern shown in table 25 (Paustian et al., 2004) would need full consideration at the national level.

**Table 25. Issues to be considered in establishing a programme on mitigation in agriculture**

| Key areas | Key concerns |
|---|---|
| **Full greenhouse gas (GHG) accounting** | - Should it cover all GHGs? And all sources?<br>- Should all land use be accounted for in meeting a country's obligation or only a subset of the land considered under the Kyoto Protocol? |
| **Measurement of sequestration and emission rates** | Are the policies or instruments for controlling and monitoring GHG emissions and carbon sinks in place? |
| **Permanence** | In the case of carbon (C) sequestration, the practice can be reversed by releasing stored C back to atmosphere. What would be the value of temporary C storage? What would be the value of a tonne GHG sequestered today in relation to a tonne sequestered in the future? |
| **Adoption** | Farmers respond to increased profit possibilities. Do we need to provide sufficient incentives to encourage farmers to adopt such mitigation practices (e.g. concept of incentive compatibility in designing contract, etc.)? |

*Source*: Paustian K, Babcock BA, Hatfield J, Lal R, McCarl BA, McLaughlin S, Mosier A, Rice C, Robertson GP, Rosenberg NJ, Rosenzweig C, Schlesinger WH, and Zilberman D. 2004: *Agricultural Mitigation of Greenhouse Gases: Science and Policy Options*. CAST (Council on Agricultural Science and Technology) Report, R141 2004, ISBN 1-887383-26-3, pp.120

308. **Full GHG accounting**: Implementation of effective GHG-sequestration policies will require full accounting of GHG emissions from all sources in a country. Attention should be given to the possibility of specific agricultural actions affecting more than one GHG. For example, increasing biomass production through fertilizer use will increase C sequestration but will also increase $N_2O$.

309. In terms of land use coverage, in a national or a global accounting system in which the national government is responsible for meeting a target, all land emissions should be included. Partial accounting may raise accountability issues. For example, it may be difficult for a country to claim GHG credits from a programme that enables farmers to adopt conservation tillage but does not take into account conversions of grasslands to croplands. However, there may be cases in which total land and GHG accounting may not be required for implementation of a domestic agricultural policy or a voluntary policy. For example, a voluntary programme may be based on the amount of C sequestered by a limited number of participants or covering particular areas of concern.

310. In moving to full accounting practices, the difficulties of GHG measurement should not be underestimated. Agriculture emissions are the subject of biological variability of genetic and environmental origins. In many cases, GHG measurement technologies do not exist or are excessively expensive and complex for widespread use. There may be a high compliance cost of moving to full GHG accounting.

311. **Measurement of sequestration and emission rates**: The ability to measure, control and monitor GHG emissions from agriculture is of paramount importance for all countries. However, land-based GHG emissions are much more difficult to measure (or estimate) as compared with emissions from individual sources, such as an industrial installation. For specific agricultural activities (for example $CO_2$ emissions from soils or indirect $N_2O$ emissions from manure management) there is a high level of uncertainty associated with the estimated emissions levels.

312. **Permanence**: Despite the identified potential for C sequestration, there are concerns regarding the effectiveness of such practices and whether they can continue to contribute meaningfully to decreases in the build-up of GHG concentrations as soils eventually reach saturation level. In addition, unlike permanent abatement measures, the benefits of C sequestration can be reversed, releasing all or part of the stored C (e.g. trees can be cut, tillage practices can change, etc.). Given this possibly temporary nature and finite holding capacity, it would be important to determine what kind of measures would be necessary to ensure a more permanent C storage.

313. **Adoption**: The provision of incentives can have a catalytic role in the effective buy-in of farmers in agricultural mitigation programmes. Farmers are far more likely to respond positively to mitigation efforts if their co-benefits are highlighted (such as increased productivity and higher profits) and if such efforts are in place for an extended period of time, thus providing more security for the future.

## C. Measures for reducing emissions from agriculture

314. The deployment of mitigation measures for livestock systems and fertilizer applications will be essential if the aim is to prevent a future increase in emissions from agriculture. Despite the significant technical mitigation potential of some agricultural practices, little progress has been made in the implementation of mitigation measures on the global scale. Based on information contained in the national communications of Parties under the Convention, only some countries are implementing mitigation measures within the agriculture sector, with the majority of these relying on voluntary agreements within the scope of sustainable development goals and with GHG reductions as added value.

315. In some countries, non-climate policies have had a large impact on emissions from agricultural activities. Examples include the EU CAP and the EU Nitrates Directive. The aim of the CAP was to provide farmers with a reasonable standard of living, consumers with quality food at fair prices and to preserve rural heritage. Milk quotas introduced under the CAP in an effort to prevent overproduction of milk and support market prices have resulted in a 30 per cent reduction overall in the dairy cow population in the EU between 1990 and 2006. The EU Nitrates Directive, which was adopted in 1991, aims to ensure that groundwater nitrate concentrations do not exceed 50 mg per litre. The implementation of this directive has resulted in decreased rates of soil N applications.

316. Another example of an international collaborative effort is the Methane to Markets Partnership, which aims to advance cost-effective, near-term $CH_4$ recovery and use as a clean energy source. The goal of the Partnership is to reduce global $CH_4$ emissions in order to enhance economic growth, strengthen energy security, improve air quality and improve industrial safety. One of the areas that the Partnership currently focuses on is $CH_4$ emissions from animal waste management.

317. It should be emphasized that there is no one size fits all when considering which measures should be implemented at the national level. Each country would have to decide on key issues for its mitigation

strategy portfolio, recognizing its national environmental, social and economic circumstances. For example:

(a) Countries having large areas covered by natural grass formation could focus on pasture management practices;

(b) Countries with extensive pastoral systems could focus their efforts on animal selection practices to improve animal efficiency rather than on breeding programmes;

(c) Countries with intensive production systems (dairy cows, poultry and swine systems) could explore the use of more expensive mitigation options, provided the costs are not prohibitive;

(d) Countries producing large amounts of manure in confined systems could explore CDM projects or other trading schemes.

318. Examples of measures to support mitigation in the agriculture sector are presented in table 26.

**Table 26. Examples of measures to support mitigation of greenhouse gases in agriculture**

| Mitigation practices | Specific mitigation practices | Measures | Administrative, institutional and political considerations |
|---|---|---|---|
| **Cropland management** | Agronomy<br>- Improved crop varieties<br>- Extending crop rotation<br>- Avoiding/reducing use of bare or fallow land | **Voluntary agreements**<br>Change commodity programme to allow more flexibility and support of best management practices | **Administrative/institutional factors**<br>- Cooperation of government agencies and integration of farm programmes is essential<br>- Credit availability may constrain |
| | Nutrient management<br>- Better nitrogen application method<br>- Precision farming<br>- Use nitrification inhibitors | **Market-based programs**<br>Taxes on N fertilizer use<br><br>**Regulatory measures**<br>Limits on N fertilizer use | **Political factors**<br>- Politically sensitive due to possible negative impact on food production |
| | Tillage/residue management<br>- Reduced tillage<br>- Improved residue management | **Market-based programmes**<br>Agricultural fuel taxes | **Administrative/Institutional Factors**<br>- Cooperation of government agencies and integration of farm programmes is essential |
| | Water management (irrigation and drainage)Water and nutrient management | | **Administrative/institutional factors**<br>- Requires regional coordination of water scheduling |
| | Rice management water, residue and nutrient management | | |
| | Agroforestry Planting trees in cropland as shelter belts, buffer strips, etc. | | **Administrative/institutional factors**<br>Cooperation of government agencies and integration of farm programmes is essential |

**Table 26** (continued)

| **Mitigation practices** | **Specific mitigation practices** | **Measures** | **Administrative, institutional and political considerations** |
|---|---|---|---|
| | Set-aside, land-use change<br>Reversion of cropland to another land cover | **Voluntary agreements**<br>Change commodity programme to allow more flexibility and support of best management practices | |
| **Grassland management** | Herd management (stocking rate, rotational grazing, grazing timing and elimination of non-productive animals) | **Regulatory measures**<br>Restriction of land aimed at increasing efficiency | |
| | Pasture productivity increase (species introduction, nutrient management, irrigation, practices to improve topsoil physical conditions, water availability and/or grass growth and hay collection) | **Voluntary agreements**<br>Research programme<br>- Local, national and regional development of improved forage varieties and cultivars<br>- Soil, water and vegetation management practices<br>**Regulatory measures**<br>- Restriction of land use? aimed at increasing efficiency<br>- Restriction of N application<br>- Controlled species introduction | **Administrative/institutional factors**<br>- Cooperation of government agencies and integration of farm programmes is essential<br>- Credit availability may constrain<br>- Incentive availability needed |
| | Fire management | **Regulatory measures**<br>- Restriction of the use of fire | |
| | Physical treatment of forage and plant breeding programmes | **Voluntary agreements**<br>- Research programme<br>- Local and regional development of improved forage varieties and cultivars<br>- Controlled species introduction | **Administrative/institutional Factors**<br>- Cooperation of government agencies and integration of farm programmes is essential<br>- Credit availability may constrain |
| | Restoration of organic soils<br>Reduction in drainage of organic soils | | **Administrative/institutional factors**<br>Cooperation of government agencies and integration of farm programmes is essential |
| | Restoration of degraded lands<br>Restoration of productivity of degraded soils | **Voluntary agreements**<br>- Change commodity programme to allow more flexibility and support of best management practices | |
| | Bioenergy (soils only)<br>- Dedicated energy crops<br>- Biofuels from crop residue | **Market-based programmes**<br>- Energy pricing<br>- Removal of market barriers | **Political factors**<br>Politically sensitive due to negative impact on food production |

**Table 26** (continued)

| Mitigation practices | Specific mitigation practices | Measures | Administrative, institutional and political considerations |
|---|---|---|---|
| **High performance animal selection** | Animal selection and breeding | **Regulatory measures**<br>Restriction of land aimed at increasing efficiency | **Administrative/institutional factors**<br>Cooperation of government agencies and integration of farm programmes is essential |
| **Feeding practices** | Increase in livestock nutrient use efficiency | | |
| | Grain replacing forage | **Market-based programmes**<br>- Land pricing<br>- Increasing yield during climate constraints due to market prices<br><br>**Regulatory measures**<br>Restriction of land use aimed at increasing efficiency | **Administrative/institutional factors**<br>- Cooperation of government agencies and integration of farm programmes is essential<br>- Credit availability may be constrained |
| | Forage quality improvement by forage species inclusion, use of silage and other practices | | |
| | Including physical treatment of forage and plant breeding programmes | **Research programmes**<br>Local and regional development of improved forage varieties and cultivars | **Administrative/institutional factors**<br>- Cooperation of government agencies and integration of farm programmes is essential |
| | Mineral and salt supplementation | | |
| **Dietary additives and specific agents** | Ionophores, probiotics and propionate precursors | **Regulatory measures**<br>Controlled use | |
| **Hormonal and enzymatic manipulation** | Bovine somatotropin (bST), hormonal growth implants | | **Administrative/institutional factors**<br>Cooperation of government agencies and integration of farm programmes is essential<br><br>**Political factors**<br>Politically sensitive because of negative impact on food quality |
| **Manure management for $CH_4$ reduction** | Collecting $CH_4$ in closed environments and burning | | **Administrative/institutional factors**<br>Cooperation of government agencies and integration of farm programmes is essential<br><br>**Political factors**<br>- Enforcement of environmental laws<br>- International cooperation |

**Table 26** (continued)

| **Mitigation practices** | **Specific mitigation practices** | **Measures** | **Administrative, institutional and political considerations** |
|---|---|---|---|
| | Collecting $CH_4$ in biodigestors and using as biogas | **Voluntary agreements**<br>Development of anaerobic digester technologies<br><br>**Market-based programmes**<br>- Energy pricing<br>- Removal of market barriers | **Political factors**<br>- Enforcement of environmental laws<br>- International cooperation<br><br>**Administrative/institutional factors**<br>- Cooperation of government agencies and integration of farm programmes is essential<br>- Development of biogas producing industry |
| | Aerobic treatment (composting, co-composting, aerobic waste treatment, soil application) | **Voluntary agreements**<br>Development of aerobic digester technologies<br><br>**Market-based programmes**<br>- Reduction of costs involved for the use of biogas<br>- Reduction of risks<br>- Fertilizer pricing | **Political factors**<br>Local regulation for waste treatment<br><br>**Administrative/institutional factors**<br>- Cooperation of government agencies and integration of farm programmes is essential |
| **Manure management for nitrous oxide reduction** | Effluent management: mechanical separation of solids and liquids | **Regulatory measures**<br>Local regulation on waste management systems | **Administrative/institutional factors**<br>Cooperation of government agencies and integration of farm programmes is essential |
| | Optimal soil application of animal manures: N amount, form and timing (effluent management) | **Regulatory measures**<br>Local regulation on waste management systems<br><br>**Market-based programmes**<br>Fertilizer pricing | **Administrative/institutional factors**<br>- Cooperation of government agencies is essential<br>- Adoption of technical and financial governmental programmes needed |

319. For many of the mitigation practices in table 26, research, development and transfer of technology and provision of technical assistance would be necessary to ensure effective implementation.

### D. Challenges and barriers

320. According to the IPCC (IPCC.2007b), common barriers in adopting C sequestration activities in the agriculture sector include: maximum capacity of soils to store C; the risk of losing C stored (e.g. because of a change in soil C management); difficulties in establishing a baseline, which is the basis of assessing emissions reductions, owing to the lack of information needed in some countries or regions; a high level of uncertainty in emissions estimates and lack of information for their assessment. Other barriers include high transaction costs, high measurement and monitoring costs for emissions reductions, non-availability of investment capital, slow progress in technological development, and the need to be consistent with or break from traditional practices.

321. Although most mitigation measures are not likely to be affected by future climate change (e.g. nutrient management and grazing management), the effectiveness of some will be affected

(e.g. irrigation in regions becoming more arid). Such practices could be modified in order to maintain their efficacy as mitigation measures. For example, although climate change and other pressures could lead to C loss that has been sequestered in soils, increases in production could offset some or all of this loss.

322. It is particularly difficult to estimate actual GHG emissions from agriculture because of the high degree of spatial and temporal variability associated with the underlying causes of these emissions. The spatial variability arises from the variation in the biophysical environment and that in farm management. This is particularly problematic for $N_2O$ and $CH_4$, both of which present large variation across landscapes and regions leading to high uncertainties in their emissions levels (Davidson et al., 2000; Davidson and Verchot, 2000; Verchot et al., 1999; and Verchot et al., 2000). Temporal variability is driven to a large extent by inter-annual variations in local weather and by the response of farmers to these variations.

323. Establishing reliable reporting procedures, under a national GHG inventory framework, requires the availability of reliable data on a host of parameters, including statistical information for agricultural activities. Where such data are not readily available, or in case of large discrepancies between different datasets agriculture and forestry research institutions can assist in developing appropriate data sets and emission factors and biomass expansion factors.

324. The majority of current mitigation measures are related to management practices, and their implementation does not depend on costly or complex technological changes. The main barriers in their implementation are cultural (education and information gaps, and inconsistency with traditional local practices) and lack of incentives (mainly financial). When dealing with options requiring new technologies or technical support, additional barriers are the costs associated with these new technologies, property rights, specific knowledge about the technology application, and potential rejection from consumers and through national regulations.

325. Technological development will be a key driver ensuring the availability of more options in the future. In this regard, governments could play an important role by providing policy and economic incentives that would support the promotion and global sharing of innovative technologies (IPCC. 2007b).

326. As mentioned earlier, the implementation of mitigation measures in agriculture would require significant resources. Government spending patterns vary across regions and have changed significantly over the past three decades (see table 27). Globally, government expenditures in agriculture are increasing in real terms by about 2.5 per cent annually. In Africa, such expenditure increased at an annual rate of about 1.5 per cent. Agricultural expenditures are highest in Asia and more than doubled in the past two decades, with an annual growth rate of around 4.0 per cent. Latin America and the Caribbean was the only region that reduced its spending on agriculture, but there was some recovery cost between 1990 and 2000 (Fan et al., 2007; Verchot et al, 2007).

327. However, despite the growth in absolute numbers, relative to total government expenditure, the share of agriculture has been decreasing, indicating a possible change in priorities. In Asia, agriculture accounted for 9 per cent of government spending in 2002, which is down from 15 percent in 1980. In Latin America, spending on agriculture was only about 2.5 per cent of total government expenditure (Verchot et al, 2007). A similar pattern also emerges when we take agricultural expenditure as a percentage of the GDP generated by the sector. In 2000, government expenditure on agriculture in developing countries corresponded to about 10 per cent of the agricultural GDP (as compared with 20 per cent in developed countries), having decreased since 1980 (Fan et al., 2007).

**Table 27. Total national agricultural expenditure in developing regions**
*(values in billions, taken at 2000 United States dollars)*

| | Year | | |
|---|---|---|---|
| **Region** | **1980** | **1990** | **2000** |
| Africa | 7.33 | 7.85 | 9.90 |
| Asia | 74.00 | 106.54 | 162.84 |
| Latin America/Caribbean | 30.48 | 11.52 | 18.16 |
| **Total** | 111.81 | 125.91 | 190.90 |

*Source:* Adapted from Fan S, Yu B and Saurkar A. 2007. Public Spending in Developing Countries: Trends, Determination and Impact. *In* Fan S (ed.) *Public Expenditures, Growth and Poverty in Developing Countries: Issues, Methods, and Findings*. Baltimore: The Johns Hopkins University Press.

## E. Opportunities and synergies

328. In order to ensure the maximum effectiveness of agriculture mitigation policies and measures, they should be integrated within a comprehensive national strategy, comprising well-focused high-level objectives, specific goals, a set of supporting instruments and locally adapted action programmes.

329. It is imperative to recognize that agricultural mitigation measures not only offer reductions in GHG emissions, but have other social, economic, and environmental benefits, particularly as regards sustainable development, food security, and making progress towards meeting the objectives of the Millennium Development Goals. Current initiatives suggest that synergies between climate change policies, sustainable development and improvements in environmental quality will most likely lead the way to realize fully the mitigation potential in this sector. Examples of possible synergies for mitigation measures in the agriculture sector include:

(a) Cropland management (through management of nutrients, tillage, residues and agroforestry) could improve ground water quality and the environmental health of the cultivated ecosystem, thus offering to local communities sustainable supplies of clean water as well as better soil and air quality;

(b) Yield improvement measures can enhance food security by increasing productivity while contributing towards a higher income for farmers, and thus helping to alleviate poverty;

(c) C sequestration combines abatement with climate change adaptation in vulnerable smallholder farming systems, thus enhancing sustainable land management and reducing poverty in rural areas of the developing world (Verchot et al., 2007).

330. There are also interactions between mitigation and adaptation in the agriculture sector that may occur simultaneously but differ in their spatial and geographic characteristics. The main climate change benefits of mitigation actions will emerge over decades, but there may also be short-term benefits if the drivers achieve other policy objectives. Conversely, actions to enhance adaptation to climate change impacts will have consequences in the short- and long-term.

331. Particularly for livestock, one of the most promising approaches for mitigation is to improve the efficiency of agricultural practices. Although more non-$CO_2$ emissions would be expected because of such an approach, the gains in terms of efficiency improvements will be reflected by a lower emission rate per unit of output (translating into a reduction of the pressure on natural resources, such as land and water). If the goal of improved efficiency is complemented with policies dealing with fixing production levels, the total emissions could be reduced (less animals to match the production level).

332. While opportunities and synergies for the majority of mitigation options can be identified, potential negative social, economic and environmental impacts should not be overlooked. For example,

improved yield could negatively affect traditional practices and the aesthetic/amenity values of local communities; restoration of degraded lands could lead to reductions in cropland that could in turn threaten the stability of food production; and bioenergy crops could lead to loss of biodiversity. Such potential negative impacts do not negate the co-benefits mentioned above. However, they should be taken into consideration (in the context of national and local circumstances) when deciding on appropriate mitigation options at the national level.

# X. Closing remarks

## A. Recommendations for future work

333. Agriculture is a significant contributor to GHG emissions and the outlook for reducing GHG emissions from this sector suggests significant potential. Further work is needed to improve the assessment of GHG emissions from agriculture, to find better ways to manage lands to improve environmental quality, to design efficient policies to implement mitigation options, and to strengthen the potential of agriculture to contribute to producing renewable energy. Identifying the 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.

334. The availability of country-specific information on the mitigation potential of different practices for agriculture (taking into account country-specific characteristics of the sector and the possible impact of existing policies and measures) will help countries design the most appropriate portfolios of mitigation practices. The information on mitigation potential contained in the IPCC AR4 provides a good starting point but does not provide the necessary level of regional/national disaggregation needed for national implementation. In tables 28, 29 and 30 relative mitigation potentials for different 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.

335. Practices that sequester C can maintain and increase soil organic matter, thereby improving soil quality and fertility, increasing water-holding capacity and reducing erosion. The AR4 mentioned some common barriers to adoption of C sequestration activities in agricultural lands, including: (i) the limit or the maximum capacity for the ecosystem to store C; (ii) reversibility in C gains; (iii) selection of an appropriate baseline; (iv) uncertainty in emissions reduction mechanisms and measurements; (v) transaction costs; and (vi) measurement and monitoring costs. These barriers have to be addressed so that potential mitigation practices will be more competitive and attractive to target users.

336. More efficient use of N and other farm inputs is critical in reducing GHG emissions and nutrient run-off, as well as in improving water quality of both surface and ground waters. Continuing research and development is likely to increase the potential of a number of mitigation options in agriculture in the long term. For instance, better use of fertilizer through precision farming, wider use of slow-and controlled-release fertilizers, nitrification inhibitors, and other practices that reduce N application (and thus $N_2O$ emissions) will enhance crop productivity (higher yields) and could improve environmental quality.

337. Bioenergy, through recycling of agricultural by-products and growing of energy crops, provides opportunities for direct mitigation of GHG emissions from fossil fuel offsets. However, there are barriers in terms of technologies and economics in the use of agricultural waste and the conversion of such waste into commercial fuels which need to be addressed. Development of innovative technologies and appropriate government investment and backing would be useful in realizing the potential of biofuel production from agricultural residues and energy crops to contribute to GHG mitigation in a more competitive manner.

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

339. Crop–livestock–forestry integration systems are recognized as an effective and sustainable mitigation approach for both developed and developing countries. However, further field measurements and research would need to be carried out in order to verify the real potential of such an approach.

### B. Possible issues for further consideration

340. When considering mitigation in the agriculture sector within the context of the AWG-LCA, other elements addressed by the Bali Action Plan may have to be considered. Such elements include: technology transfer and/or dissemination, investment and financial needs for the implementation of available and future practices; and the need for capacity-building to enable developing countries to implement relevant mitigation strategies and programmes, as well as research and development.

341. During the deliberations under the AWG-LCA, some Parties have proposed that agriculture could be a candidate for the implementation of cooperative sectoral approaches and sector-specific actions to enhance implementation of Article 4, paragraph 1 (c), of the Convention. Within this context, Parties may wish to focus their discussions on mitigation of emissions from the agriculture sector by identifying:

(a) Priority mitigation activities for the agriculture sector, taking into account the information provided in this technical paper;

(b) Links between actions at the national, regional and global levels. Given the current structure of the agriculture sector, which involves all developed and developing countries as both producers and consumers of agricultural produce, it would be important to consider how opportunities for regional cooperation, sectoral agreements and nationally driven actions can contribute to (or fit under) a global agreement on climate change;

(c) The level of resources needed and the mechanisms required for mobilizing these resources to 'green' agricultural production, while ensuring the sustainable development of the economies of all countries within the context of increasing world population and climate change;

(d) Arrangements that would be necessary to ensure that mitigation activities actually deliver the expected emissions reductions and to promote the implementation of best practices and use of the best available technologies;

(e) Ways and means on how to enhance existing (or create new) instruments and mechanisms based on market approaches that could be applied to the agriculture sector (e.g. programmatic and/or sectoral CDM, sectoral no-lose mechanisms, etc.);

(f) Opportunities for technology deployment and enhancement of technology research and development in key areas in the agriculture sector;

(g) Key challenges in measuring, reporting and verifying emissions reductions from emission abatement practices of the agriculture sector;

(h) The difference between technical versus economic potential in the agriculture sector and the implications of this.

342. The issues described in this paper could inform Parties at the upcoming AWG-LCA discussions on the challenges and opportunities for mitigation in the agriculture sector, including the discussions at the workshop on agriculture to be held in March–April 2009.

Annex I

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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 ($CH_4$)<br><br>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;<br>- Lack of or poor statistics;<br>- Market influences (more food needed);<br>- Increase in the cost of the product;<br>– Variability in the meat market;<br>- Increasing 'green market'. | Increased sustainability of pastures and carbon sequestration, avoiding degradation of more lands | May affect rural employment and food provision<br>May increase meat and milk costs, thus limiting their consumption in poor communities |
| **High performance animal selection** | Animal selection and breeding | $CH_4$<br>$N_2O$ (*) | $CH_4$<br>*Dairy Cows*:<br>0.4–5 %<br>*Beef Cattle*:<br>0.6–7 %<br>*Sheep*:<br>0.04–0.4 %<br>*Dairy Buffaloes*:<br>1–0.3 %<br>*Non-Dairy Buffaloes*:<br>2–7 %<br><br>$N_2O$: 3% | Emissions Factors by experimental measurements.<br><br>Tier 1 or Tier 2 (2006 IPCC Guidelines, Volume 4; Ch.10) | - Breeding: barriers are research facilities, financial funds for long-term programmes<br>- Farm selection: barriers are farmers' education and specific technical information.<br>- 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.<br>Grain supplementation.<br>Improvement in forage quality, mineral and/or salt supplements. | $CH_4$<br>$N_2O$ | $CH_4$:<br>*Dairy Cows*:<br>1–18 %<br>*Beef Cattle*:<br>1–14 %<br>*Sheep*:<br>1–4 %<br>*Dairy Buffaloes*:<br>4–10 %<br>*Non-Dairy Buffaloes*:<br>2–5 %<br>$CH_4$: 5 % for every 10 % of individual productivity increase. | *Option 1*:<br>Tier 3.<br>*Option 2*:<br>Emission Factors (field/ experimental measurements) and Tier 2 for emissions.<br>*Option 3*:<br>Emission Factors and emissions by Tier 2 (2006 IPCC Guidelines, Vol. 4; Ch. 10) | Main barriers include:<br>Research and laboratory facilities, technical information on the advantages of improving animal performance.<br>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.<br>Higher profitability in production systems of animal products. | Risk of increasing $N_2O$ emissions from manures and soils where manure is applied.<br>Risk of mineral/salt supplementation having an effect on human health. |
| | Increase in livestock nutrient use efficiency. | $NO_2$<br>$CH_4$<br>$CO_2$ | $NO_2$: 6–45 %<br>$CH_4$: Not estimated<br>$CO_2$: 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. | $CH_4$<br>$N_2O$ | $CH_4$: 17–40 %<br><br>$N_2O$: 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.<br>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.<br>Plant breeding programmes. | $CH_4$<br>$N_2O$ (*) | | | Research and laboratory facilities.<br>Economic analysis of cost-benefit.<br>More accurate methodologies needed | Incentive programme to animal productivity. | |
| | Mineral and salt supplementation. | $CH_4$<br>$N_2O$ | $CH_4$: Not estimated<br>$N_2O$: 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:*<br>0.3–8 %<br>*Beef Cattle:*<br>0.4–9 %<br>*Sheep:*<br>0.02–0.4 %<br>*Dairy Buffaloes*:<br>1–3 %<br>*Non-Dairy Buffaloes:*<br>0.4–1.2 % | Emission Factors by experimental measurements.<br>Tier 2 to estimate emissions (2006 IPCC Guidelines, Vol.4, Ch. 10) | Uncertain if reduction responses are sustained in time.<br>Main barriers are: Research and laboratory facilities.<br>Commercial availability of products<br>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.<br>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 %<br>$CH_4$ in vitro: 21–25 %<br>$CH_4$ in field: Variable results | | | | |
| | Use of *Probiotics* | $CH_4$ | $CH_4$ for dairy beef: ± 7 %<br>$CH_4$: 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 $CH_4$:<br>For bST 15 %<br>For other hormones and enzymes not estimated. | | Main barriers:<br>Reluctance of consumers to buy due to the presence of hormone residues.<br>Substances used for hormone manipulation is illegal in some countries.<br>Costs involved. | $CH_4$ emission reduction, as co-benefit of improving animal performance. Compatible with sustainable development.<br>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.<br>Species introduction.<br>Nitrogen fertilization, fire management and improvement of topsoil physical conditions | $CH_4$<br>$CO_2$<br>$NO_2$ (*) | $CO_2$: 0.11–0.81<br>$CH_4$: 0.02<br>All: 0.13–0.81<br><br>(units: t $CO_2$ eq $ha^{-1}$ $yr^{-1}$) | Enteric emissions:<br>Tier 2 for Emission Factors and emissions (2006 IPCC Guidelines, Vol.4, Ch.10).<br><br>Soils $N_2O$ emissions: 2006 (2006 IPCC Guidelines, Vol.4, Ch.6, Grasslands) | No technological barriers.<br>Main barrier is the cultural background of farmers and the availability of certain inputs (for example selected seeds).<br>Economic incentives, information and technology transfer are needed | Compatible with sustainable development.<br>Improving the environmental sustainability of pastures.<br>Reducing soil erosion and desertification.<br>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* | $CH_4$<br>$CO_2$ | Not estimated | | | | |
| | *Species introduction* | $CO_2$<br>$NO_2$ (*) | Maximum 20 % from new forage cultivars | | | | |
| | *Nitrogen fertilization and fire management* | $CO_2$<br>$NO_2$ | $NO_2$: 5 %<br>$CO_2$: Reduction not estimated | | | | |
| | *Improvement of topsoil physical conditions* | $CO_2$<br>$NO_2$ | $N_2O$: 7–11 % | | | | |
| | *Including physical treatment of forage and plant breeding programmes* | $CH_4$<br>$N_2O$ (*) | Not estimated | | More accurate methodologies needed.<br><br>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. | $CO_2$<br>$CH_4$ | $CO_2$:<br>1.54–2.79<br>$N_2O$:<br>Non estimated<br>All:<br>1.54–2.79<br><br>(units: t $CO_2$ eq $ha^{-1}$ $yr^{-1}$) | Tier 1<br>(2006 IPCC Guidelines Vol. 4, Ch. 10) | The lack of appropriate incentives and information may be the main barrier.<br>There is a lack of a network of enterprises and experts who give support to biogas technology.<br>Lack of legal background. Technology transfer and incentive programmes are needed. | Win-win option.<br>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 %<br>$NO_2$:<br>Non estimated | | | | |
| | *Collecting $CH_4$ in biodigestors and using as biogas* | | $CH_4$: 90 %<br>$NO_2$: 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 %<br>$CH_4$: increase N/E<br>$CO_2$: increase N/E | Option 1: parameters from field measurements; then tier 2.<br>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 %<br>$CH_4$: increase N/E<br>$N_2O$: 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 | $CH_4$<br>$N_2O$ | Not estimated for $CH_4$ or $N_2O$ | National regulations.<br>Research and laboratory facilities. | Biotechnology research programmes. | Potential environmental effects of transgenic material. |
| **Dietary additives and specific agents** | Changing rumen micro flora activity:<br>Use of bacteriocins, halogenated compounds, chloroform, vaccine against methanogens, and other $CH_4$ producer inhibitors. | $CH_4$ | Homogenate compounds: 54 %<br>Saponins: Not estimated<br>Nisin: 36 %<br>Immunisation up to 70 %<br>Vaccines: 11–23%<br>Other inhibitors: 17–100 %<br>Bovicin HC5 in vitro: 50 % | Sustainability of animal responses to the practice, not yet well understood.<br>Environmental effects of animal residues. | Sustainability of animal responses to the practice and environmental effects of residues released into the environment.<br>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 %<br>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:**<br>Agronomy | Soil carbon increase:<br>0.2–0.88 t $CO_2$ $ha^{-1}$ $yr^{-1}$ (mean ranges)<br>Direct $N_2O$:<br>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:**<br>Nutrient management | Soil carbon increase:<br>0.26–0.55 t $CO_2$ $ha^{-1}$ $yr^{-1}$ (mean ranges)<br>Direct $N_2O$:<br>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.<br>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:**<br>Tillage and/or residue management | Soil carbon increase:<br>0.15–0.70 t $CO_2$ $ha^{-1}$ $yr^{-1}$ (mean ranges)<br>$N_2O$:<br>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.<br>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:**<br><br>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.<br>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:**<br><br>Rice management | $CH_4$:<br>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:**<br><br>Agroforestry | Tree biomass carbon increase:<br>1- t $CO_2$ $ha^{-1}$ $yr^{-1}$.<br>Soil carbon increase:<br>0.15–0.70 t $CO_2$ $ha^{-1}$ $yr^{-1}$.<br>$N_2O$:<br>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.<br>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:**<br><br>Set-aside, and land-use change | Soil carbon increase:<br>1.61–3.04 t $CO_2$ $ha^{-1}$ $yr^{-1}$<br>$CH_4$:<br>0.02 t $CO_2$ eq $ha^{-1}$ $yr^{-1}$<br>$N_2O$:<br>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:**<br><br>Grazing, fertilization, fire practices | Soil carbon increase:<br>0.11–3.04 t $CO_2$ ha $^{-1}$ yr $^{-1}$<br>$CH_4$:<br>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.<br>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<br>Nutrient management increases productivity (food security), improves soil quality, promotes water conservation and conservation of other biomes, and supports biodiversity and wildlife habitat.<br>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 $^{-1}$<br>$N_2O$:<br>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)<br>$CH_4$:<br>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$^{-1}$<br>$N_2O$:<br>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.<br>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<br>Indirect $N_2O$:<br>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<br>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.<br>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.