

Key trends in emissions from agriculture and use of policy instruments

Agriculture: trends and prospects for emission cuts

Where are emissions from?^{1,2}

Agriculture is the largest global source of anthropogenic non-CO₂ emissions (Table 1 and Oenema et al, 2001; IPCC, 2006), but a small (c.15%) and declining source of CO₂ emissions (Bruinsma, 2003). Until the late 1990s land use change, particularly deforestation was the main source of agricultural emissions (IPCC, 2001). This is no longer the case globally but it is still an issue in a few countries, e.g. in Brazil where livestock ranching continues to be a major cause of deforestation. The largest single source is now the soils of existing crop and pasture land because of various emissions resulting from ploughing, tillage and irrigation practices, and the application of livestock manure and synthetic fertilisers. The methane emissions from irrigated rice are more correctly attributed to this soil related category, because bacteria growing in the soil and flood irrigation waters under anaerobic conditions release methane which is taken up by rice roots and passes through the plant before being emitted to the air. Although even here the picture is complex, because much of the methane from rice fields stems from the application of livestock manure.

Table 1 Agriculture's contribution to global non-CO₂ greenhouse gas emissions^{a)}

Gas from AE ^{b)}	Agricultural source	Percent of TGE ^{b)}	Percent of TAS ^{b)}
		-----%	
Methane	Ruminants	15	49
	Rice production	11	
	Biomass burning	7	
Nitrous oxide	Livestock ^{c)}	17	66
	Mineral fertilizers	8	
	Biomass burning	3	

^{a)}Cited from Lassey *et al.* (2000), Bouwman (2001) and Bruinsma, 2003.

¹ It is important to distinguish between CO₂ and non-CO₂ GHGs . First, because of the GWP differences between them. Secondly, because reduction of non-CO₂ GHGs brings environmental and economic benefits additional to the climate change benefit e.g. decreased acidification of freshwater ecosystems and soils, and less eutrophication.

² There is large uncertainty about the emission coefficients for individual sources, for example, the IPCC coefficient for N₂O emissions from nitrogen fertiliser is 1.25 +/- 1.0% but large spatial and temporal variation in emissions make it extremely difficult to derive average values. Similarly, average methane values are also difficult to determine because of the wide variation in manure quality and storage conditions, e.g. estimates for methane emissions from manure in Brazil are 70% higher when locally derived coefficients are used rather than the generalised ones of the EPA.

^{b)}AE: agricultural emissions; TGE: total global emissions; TAS: total anthropogenic sources.

^{c)}Including the manure applied to farmland.

However, from a policy perspective the most important, and in production chain terms, the largest source of emissions is livestock. First, because it is the source of substantial direct emissions of methane released by ruminants as a by-product of the digestive process (enteric fermentation). Second, it is a major indirect source of GHG emissions including:

- N₂O released in the production of feed grains and pastures. On average feed grains account for c 25% of nitrogen fertiliser use, and hence of 25% of the CO₂ released in the manufacture of such fertilisers – at the national level this proportion can be even greater, for example, in Brazil and the UK about 40% and 70% of nitrogen fertilizer use, respectively, is applied to crops and pastures that are used for livestock production (Steinfeldt, 2006);
- emissions arising from manure storage and application to crops (Clemens & Ahlgrimm, 2001);
- secondary emissions of N₂O stemming from the very large amounts of gaseous ammonia that are subsequently returned to the soil through dry and wet deposition (van der Gon et al, 2004).

Third, because a higher proportion of the direct and indirect emissions from livestock are N₂O (EPA, 2004) which is a more powerful GHG than methane. And finally, the emissions from livestock are projected to grow more rapidly than those from cropland (see section on growth of emissions to 2050). Thus globally about 53% of the emissions come from livestock, rising to around 70% in Brazil.

China, India and the USA are the three largest emitters in that order, together accounting for c. 45% of global agricultural emissions of non-CO₂ GHGs (EPA, 2004), although in per capita terms the USA is the largest emitter by a substantial margin. Country-level analysis gives a misleading representation of the environmental footprint of each country because of agricultural trade. For example, China and the EU are large importers of livestock feed with their environmental footprint stretching to Argentina, Brazil, and the USA which supply them with soya beans. Argentina and Brazil export 25-50% of their coarse grain and oilseed production (FAOSTAT, 2005).

Drivers behind growth

Historically, income and population growth have driven demand for total agricultural output, modified in some countries by cultural/religious factors, and hence have been the main drivers for agricultural GHG emissions. In the future income growth will be the dominant driver for agricultural output. Increased crop production will come primarily from the intensification of production using synthetic fertilisers and other modern inputs rather than converting forest or grazing land to cropland since most countries have little or no land left to develop. Increased livestock production will come from the greater use of feed grains and oil seeds. Consequently, future increases in agricultural emissions

will result primarily from changes in agricultural practices driven by the physical and/or economic need to increase output per unit of land.

Growth in emissions to 2050

Two factors will dominate growth: changes in the demand for food and technological progress. The slow down in demand for food and feed crops which is likely to be of the order of 1% over the next 50 years at the global level though higher at the regional level (FAO, 2006). This will drive the demand for nitrogen fertiliser but this is likely to be at a slower rate than projected by the EPA (that is, c.1.5% per year). They assume the continuation of recent trends, which were -0.8% per year in period 1996/97-2002/03, and are projected to be c.1.3% per year over the next 4-5 years (FAOa, 2004). However, the projected reduction in crop demand and the probability of modest gains in fertiliser use efficiency (Bruinsma, 2003; Cassman et al, 2003; Mosier et al, 2004) could result in 2000-2030 average annual growth rate of about 0.6% (FAOb, 2004 and Tenkorang, 2005), so most crop related emissions could rise at a similar rate, and are likely to be even slower thereafter. The situation for the livestock sector is different because income growth and changes in consumption preferences in developing countries is likely to drive the demand for meat and milk products at a much higher rate, possibly as much as 2.0% up to 2030 but slowing to 1% in 2030- 2050 (FAO, 2006). Some technological progress in the livestock sector can be expected over this period but major increases in GHG emissions are likely unless there is a substantial expansion of biogas using livestock wastes.

How much can we cut emissions?

The greatest physical potential is from the application of conservation tillage to sequester soil C, though there is uncertainty about how much of this potential can be achieved in practice, and what the net gain will be in the long-term if rising global temperatures increase the rate of soil organic matter breakdown. However, it is clear that conservation tillage, as with many of the following measures to lower methane and N₂O emissions, can be justified on current economic and environmental grounds.

Most studies that have examined the potential for gains in N use efficiency point to a gain of c.0.6% per year over the next 25-50 years (see above).

Agriculture: policy instruments for cutting GHG emissions

There is a range of possible interventions that are technically feasible and commonly economically beneficial Oenema et al, 2001; Clemens & Ahlgrimm, 2001; IPCC, 2006. However, there are a number of constraints to their adoption. For example, (a) they may involve tradeoffs between different gases that cannot be completely resolved, with measures to reduce the emission of one GHG often intensifying the emission of another GHG so the net effect on GWP may not be clear cut; and (b) some of them are not suitable for the majority of developing country farmers e.g. because of their high capital requirements. On the other hand a number of interventions present win-win situations because they have other economic and/or environmental benefits in addition GHG reduction (Norse, 2005).

Soils & Rice

Three types of intervention deserve greater attention.

Increasing carbon sequestration.

Opportunities include the wider adoption of conservation tillage (CT) with additional environmental and economic benefits. These benefits include:

- reduced soil erosion and loss of plant nutrients, and improved nutrient availability.
- higher rainfall infiltration and soil moisture holding capacity and therefore lower vulnerability to drought.
- savings in fossil fuel use of 55-78%.
- Increased crop yields (4% for maize, 7% for wheat and 32% for soyabean) and higher incomes.

This will need a number of policy interventions including:

- Development of national strategies to encourage the development and uptake of CT
- Awareness raising - few government officials, farmers and extension workers understand the importance of CT
- International co-operation to build up the capacity for testing and developing CT equipment suitable equipment for small farmers
- R&D on CT technologies

Other important opportunities include the spread of agro-forestry and the rehabilitation of degraded crop and pasture land.

Raising fertiliser use efficiency (FUE)

There is a large gap between developed and developing countries in FUE. In China and India, the world's largest users of N fertiliser the low FUE is commonly related to the overuse and/or poor management of synthetic fertilisers but much can be done to correct this (Case study 1).

Policy Case Study 1: Lowering China's N₂O emissions from soils

China has the largest non CO₂ agricultural emissions in the world, including about 25% of N₂O emissions (Norse, 2005), which given current policies are likely to grow at c.2% per year for the next 15 years before falling to <1% per year (Zhu et al, 2006). A large proportion of these N₂O emissions result from the overuse and/or mismanagement of synthetic nitrogen (N) fertilisers and livestock manures. This overuse is worst on cereals and vegetables, and can be 25-50% more than the agronomic and economic optima, with application rates double or more those used in developed countries. The overuse also contributes acid rain and severe eutrophication of the China Sea (Duan et al, 2000). Moreover, there are serious social costs in terms of a circa 15% reduction in net farm incomes because farmers are applying fertilisers well above the economic optimum level and environmental damage that lowers crop yields and requires corrective measures such as water treatment to lower nitrate levels in drinking water (Zhang et al, 2006). Thus lowering N₂O is a clear win-win situation with local, national, regional and global benefits (Norse, 2005).

The reasons for N fertiliser overuse are complex and include weak advisory services, distorted economic incentives, and inadequate regulations so a suite of complementary policy interventions is required. Public advisory services must be reformed and alternative mechanisms are needed for giving farmers sound advice. Fertiliser quality and fertiliser and manure use regulations need to be tightened and implemented. R&D is required on simple, low cost testing kits for plant nutrient requirement and on cost-effective slow release N fertilisers. Economic incentives must be designed to stop extension workers encouraging the overuse of N fertiliser, and ensure full economic costing of fertilisers and irrigation water.

In the medium term these interventions could:

- Lower N fertiliser production by c. 25% giving a major reduction in CO₂ and N₂O emissions from the fertiliser industry.
- Reduce N fertiliser use by 5-6 Mt/yr and hence a reduction of direct and indirect emissions of N₂O of 20-40 MtCO₂-eq in the medium term and possibly double that in the longer term.

Interventions to limit fertiliser overuse and improve FUE include the following.

- i) Reform of the extension service and the introduction of new approaches to providing farmers with advice appropriate to their needs.
- (ii) Improvement in the quality of industrial fertilisers so that farmers feel confident that they will perform as they should and not overuse them to compensate for such uncertainties.
- (iii) Increase R&D on low cost slow release nitrogen fertilisers and nitrification inhibitors that can be used profitably by small farmers.
- (iv) Development of decision support tools for both regional planning and site-specific management.
- (v) Development of simple plant nutrient testing kits that farmers or extension workers can use to make direct measurements of how much fertiliser or manure needs to be applied to achieve good yields.
- (vi) Green taxation – introduction of pollution tax on N fertiliser. EU experience shows that the tax rate would have to be very high to reduce fertiliser use, and too high to be acceptable in developing countries. However, lower tax rates would raise awareness and the revenue could be used to finance more directly beneficial interventions.

Improving water & nutrient management for rice

Switching from flood irrigation to controlled irrigation with no flooding or with temporary drainage of soils would reduce methane emissions. Given that many farmers pay little or for their irrigation water and water supplies are under great strain in many countries the introduction of water pricing could have a major impact. However, in practice, introducing water pricing in developing countries could be difficult in the short term because they lack the institutional and technological means for doing so, and the equipment costs be too expensive for some small farmers, so there could be adverse impacts on some of the poorest communities.

Livestock

There are several important issues here. For example, there is the issue of non-point source versus point source pollution, where action to control the former may lead to greater problems regarding the latter. And there is the trade-off that can arise between water pollution control and air pollution control, with actions to control waste discharges leading to greater emissions of GHGs.

The basic problem is that up to 95% of the nitrogen in livestock feed is excreted in urine or manure and lost to the environment as ammonia and nitrogen gases, nitrate in surface runoff or leachates entering the groundwater. The techniques used for manure management can influence which of these pathways predominates. These and other synergistic effects of the pollutants released from livestock enterprises, and the multiple environmental impacts (soil and water acidification, eutrophication, acid rain, and ozone

formation as well as GHG emissions) that they have both locally and internationally, underlines the need for a holistic waste management strategy.

The main interventions are:

- (i) Raising production efficiency through better nutrition and genetic improvements to reduce methane emissions. Since these actions are aimed at improving feed conversion rates and in relative terms lowering feed requirements, they will also reduce N₂O emissions from the production of feed crops. Techniques to do this include the use of feed additives and supplements.
- (ii) Introduce or strengthen regulations on the size thresholds for livestock enterprises (LE) and the waste control requirements set for each including storage requirements. For example, LE should all require permits for point source discharges and nutrient management plans for the land receiving liquid or solid manure. These plans should take account of all sources of nitrogen (industrial fertiliser, atmospheric deposition, irrigation water and livestock manure) so that the total nitrogen (and phosphate) input does not exceed the agronomic needs of crops, as with the measures described above to limit the overuse of nitrogen fertilisers.
- (iii) Better livestock waste management through greater encouragement and support for biogas production and use, which has secondary benefits by forming a slurry that releases less N₂O than undigested slurry, and organic fertiliser production from livestock wastes on medium and large livestock enterprises.
- (iv) Use of nitrification inhibitors.

Policy Case Study 2: Improving manure management to lower global methane and N₂O emissions

Manure mismanagement currently accounts for about 8% of global non-CO₂ emissions (largely methane and N₂O). Given that the demand for livestock products and feed grains are projected to grow by >1.5% per annum for the next 25 years (FAO, 2006) and then c.1% to 2050 these emissions will also increase significantly. The emissions commonly come from poor manure storage facilities on intensive livestock farms and can be reduced with existing technologies (Clemens & Ahlgrimm, 2001). Moreover, the long term trend is for almost all of incremental emissions to come from larger and larger units.

Lowering emissions starts with improved feed quality and balance, which lowers the N content of manure as well as reducing methane production from enteric fermentation. However, the key actions are better storage and waste utilisation as part of an integrated system. Options include the relatively well established technologies, notably anaerobic digestion to optimise biogas production and reduce methane losses, and N₂O and ammonia emissions by up to 50% (FAO, 1997), and new techniques such as manure cooling (up to 20% reduction in methane losses). The uptake of these technologies has been constrained by high unit costs. However, the trend towards larger livestock enterprises should give better economies of scale, and this, together with rising fossil fuel prices should encourage faster uptake. Such technological options are not sufficient in themselves. They need to be associated with other improvements, for example, in planning regulations on the location, size and waste handling requirements of intensive livestock farms; building regulations for storage tanks and covers; and environmental protection regulations regarding the timing and rates of disposal of wastes to cropland.

Achievable reductions in methane emissions from biogas generation have been estimated at 50-75% depending on the climatic region. If one assumes that over the next 25 years the achievable reduction is 20% then there would be annual saving of some 100 Mt CO₂ equiv over the next 30 years.

Uncosted estimates of possible emission savings from agriculture

The main savings could come from four improvements in: rice production technology; nitrogen fertiliser use efficiency (NUE); livestock management – particularly feed quality; and manure management.

The improvements in rice production technology relate largely to CH₄ reduction but can involve tradeoffs between lower CH₄ and higher N₂O emissions. CH₄ emissions (c 600 Mt CO₂ –eq. per yr⁻¹ in 2000) can be lowered by (a) reducing manure use and improving residue management, (b) switching from flood to controlled irrigation and (c) new germplasm and forms of soil ecosystem management whose benefits are not readily quantifiable. It is possible that the main gains from (a) have already been achieved in China (Khali & Shearer, 2005) but it is reasonable to assume that 200 Mt CO₂ –eq. per yr⁻¹ could be saved by 2030 with limited gains thereafter. Switching from flood to controlled irrigation can reduce CH₄ emissions by 20-50% but the pressure for this change is possibly limited to the areas suffering from water shortages, that is, 25% of the flood rice area to 2030 and 40% by 2050, giving savings of c.20-50 Mt CO₂ –eq. per yr⁻¹ by 2050.

Substantial reductions in nitrous oxide emissions from fertilisers could be possible through improvements in nitrogen fertiliser use efficiency (NUE) because of widespread overuse of N fertilisers and poor nutrient management. Estimates of projected N₂O emissions are very sensitive to assumptions about gains in NUE. Assuming there is little change in harvested area to 2030, growth in N₂O emissions could range from 0.6-1.3% per year depending on the assumptions about NUE (FAO, 2003; Cassman et al, 2003).

This suggests that rigorous action to raise NUE could reduce N₂O emissions in 2030 by at least 15% compared with the business as usual case, and for China, the world's largest consumer of N fertiliser, the reduction could be more than 25% (Norse, 2005). Moreover, the experience of the developed countries suggests that further gains could be achieved up to 2050. These N₂O savings from fertiliser use will be boosted by the relative reduction in N fertiliser production (some 35 Mt in 2030) which releases about 3 t of CO₂ and 2t CO₂.eq. of NO₂ per tonne of product. In addition there will be technological gains upstream of agriculture. For example, CO₂ emissions from N fertiliser production have declined by c.300% over the past 30 years through advances in technology and further gains can be expected in the next 30 years.

Lower methane emissions from livestock could account for more than 12% of carbon savings in 2020 by improving animal breeding and diets, and expanding pasture improvement and stall-feeding methods to lower emissions per unit of output.³ These actions together with nutritional supplements and different feeding patterns (such as smaller but more frequent feeding) could help reduce methane emissions from livestock by up to 20% of 2020 baseline levels.

³ IPCC (2006) and FAO (2003)

These estimates of methane and nitrous oxide emission savings may be an underestimate because they exclude emissions from manure management, which can be reduced through better storage and waste utilisation. Options to do this include relatively well established technologies, notably anaerobic digestion to optimise biogas production and reduce methane losses, and N₂O and ammonia emissions by up to 50%, and new techniques such as manure cooling (up to 20% reduction in methane losses). The uptake of these technologies has been constrained by high unit costs. However, the trend towards larger livestock enterprises should give better economies of scale, and this, together with rising fossil fuel prices should encourage faster uptake. Such technological options are not sufficient in themselves. They need to be associated with other improvements, for example, in planning regulations on the location, size and waste handling requirements of intensive livestock farms; building regulations for storage tanks and covers; and environmental protection regulations regarding the timing and rates of disposal of wastes to cropland.

Achievable reductions in methane emissions from biogas generation have been estimated at 50-75% depending on the climatic region. If one assumes that over the next 15 years the achievable reduction is 20% then there would be annual saving of some 50 Mt CO₂ equiv.

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