Greenhouse Gas Emissions from European Croplands

Pete Smith, Per Ambus, María Cristina Amézquita, Olof Andrén, Dominique Arrouays, Bruce Ball, Pascal Boeckx, Claus Brüning, Nina Buchmann, Leandro Buendia, Pierre Cellier, Alexander Cernusca, John Clifton-Brown, Ulrich Dämmgen, Frank Ewert, Enzo Favoino, Jean-Louis Fiorelli, Chris Flechard, Annette Freibauer, Sylvie Hacala, Roland Harrison, Roland Hiederer, Ivan Janssens, Pierre-Alain Jayet, Jean-Pierre Jouany, Hermann Jungkunst, Thord Karlsson, Peter J. Kuikman, Marit Lagreid, Peter A. Leffelaar, Adrian Leip, Pierre Loiseau, Celia Milford, Albrecht Neftel, Oene Oenema, Stephen Ogle, Jørgen E. Olesen, Paula Perälä, Stelios Pesmajoglou, Søren O. Petersen, Kim Pilegaard, Antonio Raschi, Kristiina Regina, Mark Rounsevell, Sloan Saletes, René (L.M.) Schils, Bernard Seguin, Erminia Sezzi, Jean-François Soussana, Paolo Stefani, Pierre Stengel, André van Amstel, Oswald Van Cleemput, Bram van Putten, Bas van Wesemael, A. (Jan) Verhagen, Nicolas Viovy, Nicolas Vuichard, Hans-Joachim Weigel, Achim Weiske & Hans C. Willers

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• Executive Summary

Agriculture is a significant source of the three main biogenic greenhouse gases (GHGs), carbon dioxide, nitrous oxide and methane. Within the EU-15, croplands are a significant source of both carbon dioxide (78 Mt C y^{-1}) and nitrous oxide (~60 Mt C-equivalents y^{-1}). Since agricultural management is responsible for much of this flux, there is potential within the EU-15 to reduce this flux or to sequester soil carbon. Many factors drive GHG emissions from agriculture, a signifcant number of which are socio-political.

There are a number of methods available for accounting for GHGs but the most widely used are the IPCC 1996 revised guidelines. These provide default emission factors, but allow for country- / region -specific values for factors if available. Other, more sophisticated methods can also be used if available. Meta-analyses of data in Europe could help to provide better emission factors for use in Europe and in the future, dynamic emission factors (that respond to, for example, climate, soils, crop, fertiliser etc.) might replace the static default emission factors currently used. Well-evaluated process-based models, linked to a series of benchmark sites, may play a role in GHG accounting in the future. Verification of GHG emission estimates will be difficult.

Greenhouse gas emissions in 1990 and 2000 for EU-15 are estimated to be as follows: nitrous oxide-1990: 60 Mt C-equivalents y^{-1}, nitrous oxide-2000: 57 Mt C-equivalents y^{-1}, methane-1990: 54 Mt C-equivalents y^{-1}, methane-2000: 50 Mt C-equivalents y^{-1}, carbon dioxide-1990s: 78 Mt C y^{-1}. By comparing country submissions to the United Nations Framework Convention on Climate Change (UNFCCC) with estimates from IPCC defaults and other sources, discrepancies at the national level within the EU can be seen, though total EU-15 figures are similar across methods.

GHG mitigation options for croplands are examined. Per-area carbon sequestration rates are used to estimate mitigation potentials by comparing types and areas of land-management, in 1990 and 2000 and projected to 2010 for EU-15. For four country level case studies data are available: UK, Sweden, Belgium and Finland. In these countries, because cropland area is decreasing, and there are no current incentives in place to encourage soil carbon sequestration, we found that carbon sequestration has been small or negative in the EU-15 and all case study countries, except Belgium between 1990 and 2000. For all countries except Belgium, carbon sequestration is predicted to be negligible or negative to 2010, based on extrapolated trends. The only trend in agriculture that may be enhancing carbon stocks on croplands at present is organic farming, and that is highly uncertain. Previous studies have focused on the potential for carbon sequestration and have shown quite significant potential. This study, which examines the sequestration likely to occur by 2010, suggests that this potential will not be realised. Without incentives for carbon sequestration in the future, cropland carbon sequestration under Article 3.4 of the Kyoto Protocol will not be an option in EU-15.

For reducing emissions of nitrous oxide (and methane) there are a number of options that offer significant GHG mitigation, most of which rely upon better fertiliser (mineral and organic) use and water management. The livestock and manure management sectors offer greater mitigation potential for methane. There may be trade-offs between different greenhouse gases, especially between carbon dioxide and nitrous oxide, so it is important to assess potential mitigation options for their impact upon all greenhouse gases.

Future priorities include the need for a better understanding at the process level (especially in cropland soils), data / inventory collation and meta-analysis, further development of future scenarios of agricultural land-use and management, the development of new technologies and methodologies for measuring soil carbon and greenhouse gas emissions simultaneously, process studies (both modelling and experimental) to couple the carbon and nitrogen cycles and a more complete biogeochemical / physical / socio-economic assessment of GHG mitigation options in agriculture.

• Introduction

1.1 Aims of the report

This report was initiated at a meeting of invited experts held in Clermont-Ferrand, France under the auspices of the CarboEurope GHG programme. The meetings between the cropland and grassland focus groups were held jointly, since many management decisions are taken at levels that affect both cropland and grasslands, but this report is for croplands only. A separate report has been prepared for grasslands. The aim of this report is to:

- Provide up-to-date scientific information on the extent of greenhouse gas (GHG) fluxes from European agriculture, and the factors controlling GHG emissions;
- Examine the ways in which GHG emissions from agriculture are currently estimated and suggest, where appropriate, possible improvements;
- Examine possibilities to mitigate GHG fluxes from European agriculture;
- Identify key uncertainties and areas for future research.

The report is aimed at scientists and policy-makers involved in estimating GHG emissions from agriculture and in assessing mitigation measures to reduce these emissions.

1.2 Greenhouse gas fluxes from agriculture in Europe

Agricultural lands (i.e. lands used for agricultural production, consisting of cropland, managed grassland and permanent crops) occupy over 50% of Europe's land surface and fluxes from agriculture constitute the largest CO_2 flux to the atmosphere of all land uses. Estimates of the fluxes are based on few studies and research is urgently required to better quantify total agricultural greenhouse gas fluxes and reduce the uncertainty in the flux estimates. Further, because agriculture is managed, the drivers for the fluxes are complex and heterogeneous, but this management also offers the possibility of GHG mitigation.

The Marrakech Accords, resulting from the 7th Conference of Parties (COP7) to the 1992 United Nations Framework Convention on Climate Change (UNFCCC), allow biospheric carbon sinks (and sources) to be included in attempts to meet Quantified Emission Limitation or Reduction Commitments (QELRCs) for the first commitment period (2008-2012) outlined in the Kyoto Protocol (available at: www.unfccc.de). Under article 3.4 the activities: forest management, cropland management, grazing land management and re-vegetation are included. Soil carbon sinks (and sources) can therefore be included under these activities. Further, direct emission reductions of the greenhouse gases nitrous oxide (N_2O) and methane (CH_4) will help parties to meet QELRCs.

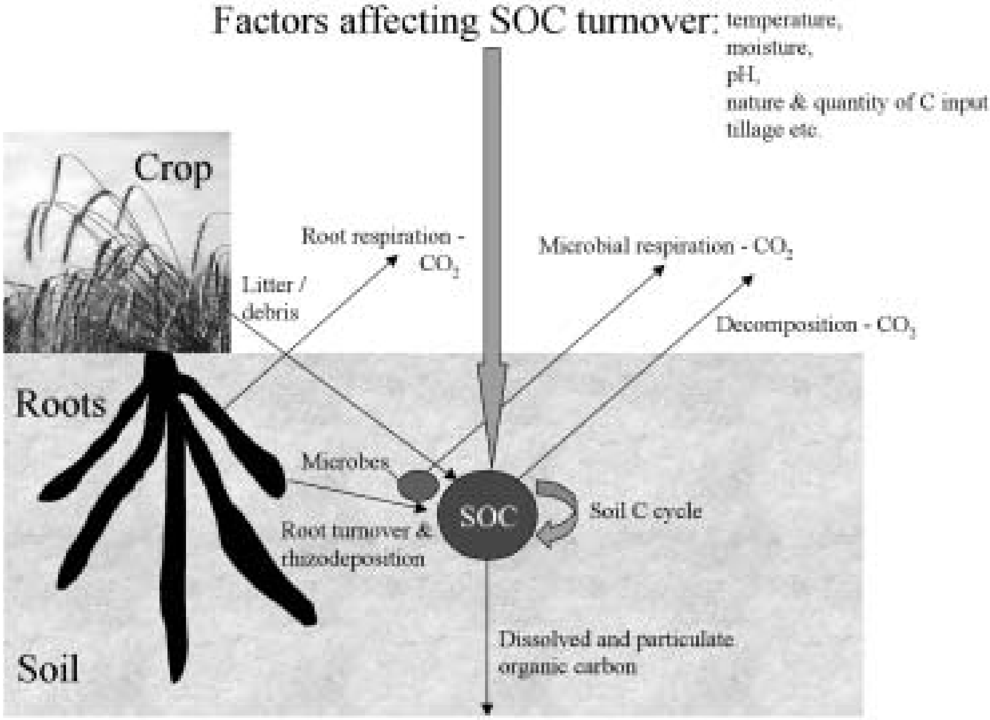
Parties electing to include cropland management, grazing land management and re-vegetation need to account for changes in these soil carbon sinks and sources on a net-net basis, that is to say, they must compare the net flux of carbon from a given activity during the commitment period with the equivalent net flux of carbon in the baseline year (usually 1990). Carbon sequestration (*viz.* CO_2 fixation) in cropland soils, or even a reduction in a flux to the atmosphere compared to the baseline year, can therefore be used by a party to the UNFCCC in helping to meet emission reduction targets. Similarly, direct emission reductions of the greenhouse gases nitrous oxide (N_2O) and methane (CH_4) from croplands can also be used. It is essential that effects of land management of all three GHGs are evaluated concomitantly.

1.3 The important greenhouse gases emissions from croplands

The main GHG emissions from agriculture are carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4).

Carbon dioxide is lost from agricultural soils by soil and root respiration and the decomposition of soil organic matter. Changes in organic carbon content are a function of the balance between inputs to soil of carbon fixed by photosynthesis and losses of soil carbon via decomposition. Soil erosion can also result in the loss (or gain) of carbon locally, but the net effect of erosion on carbon losses as CO_2 for large areas on a national scale is unclear. For soils, both the quantity and quality of organic matter inputs and the rate of decomposition of soil organic carbon will be determined by the interaction of climate, soil and land use/management (including land-use history). In native ecosystems, climate and soil conditions are the primary determinants of the carbon balance, because they control both production and decomposition rates. In agricultural systems, land use and management act to modify both the input of organic matter via residue production, crop selection, fertiliser application, harvest procedures, residue management and the rate of decomposition (by modifying microclimate and soil conditions through crop selection, soil tillage, mulching, fertiliser application, irrigation and liming; IPCC, 1997). Management practices that increase soil and root respiration cause short-term effluxes of CO_2 to the atmosphere, whilst practices that increase the rate of decomposition of organic matter lead to longer-term losses of soil organic carbon in the form of carbon dioxide (Figure 1.3a). Other losses of carbon from ecosystems result from the export of agricultural products, and the carbon in these short-lived products are assumed to be lost to the atmosphere as CO_2 shortly after final market.

Figure 1.3a Schematic diagram of carbon loss from cropland soils



Biogenic emissions of N_2O from soils result primarily from nitrification and denitrification processes. N_2O is a by-product of nitrification and an intermediate during denitrification. Nitrification is the aerobic microbial oxidation of ammonium to nitrate and denitrification is the anaerobic microbial reduction of nitrate through nitrite, nitric oxide (NO) and N_2O to N_2. Nitrous oxide is a gaseous product that may be released from both processes to the soil atmosphere (IPCC, 1997). Fungi also produce N_2O (Figure 1.3b). Major environmental regulators of these processes are temperature, pH, soil moisture (i.e. oxygen availability) and carbon availability. In most agricultural soils, biogenic formation of N_2O is enhanced by an increase in available mineral nitrogen, which in turn increases nitrification and denitrification rates. Hence, in general, addition of fertiliser N or manures and wastes containing inorganic N, will stimulate N_2O emission, as modified by soil conditions at the time of application. N_2O losses due to denitrification under anaerobic conditions are usually considered more important than nitrification-N_2O losses under aerobic conditions. Therefore no-tillage will perhaps decrease CO_2 losses, but, due to poorer aeration, enhance N_2O losses due to denitrification. A schematic representation of N_2O losses from agriculture is given in Figure 1.3c. Whilst N_2O emissions have been estimated in both process-based and inventory studies using, for example, process-based models, the outstanding problem is the uncertainty of these estimates. The uncertainty is high because N_2O as CO_2 in soils are produced biologically and emissions usually occur in "hot spots" around particles of residues and fertiliser, despite the diffuse spreading of fertilisers and manure (EEA, 2003).

Figure 1.3b Microbial transformations in the soil showing mechanisms of N_2O production

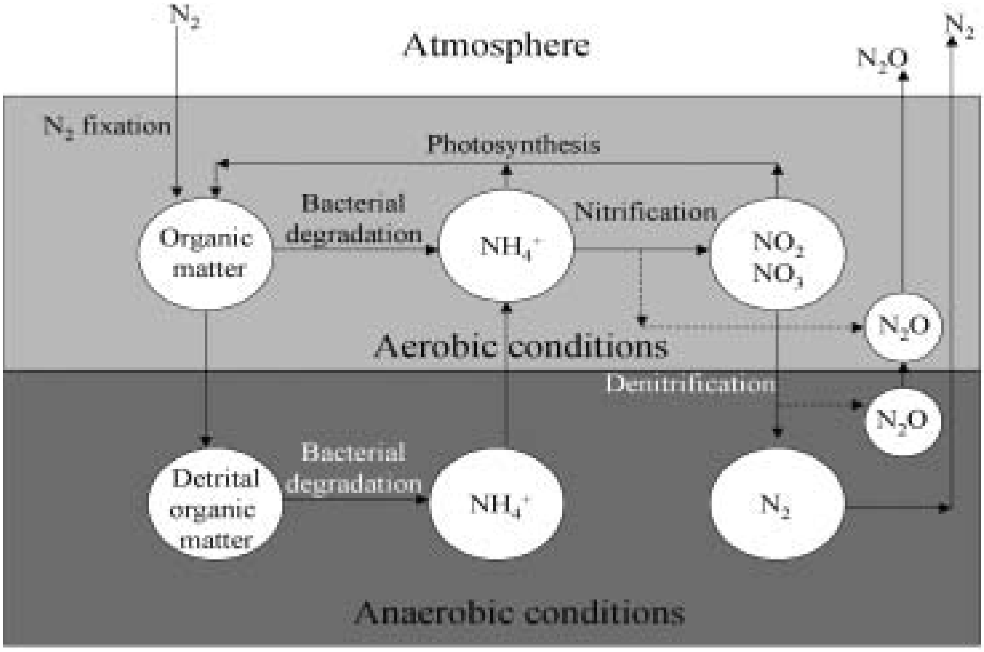
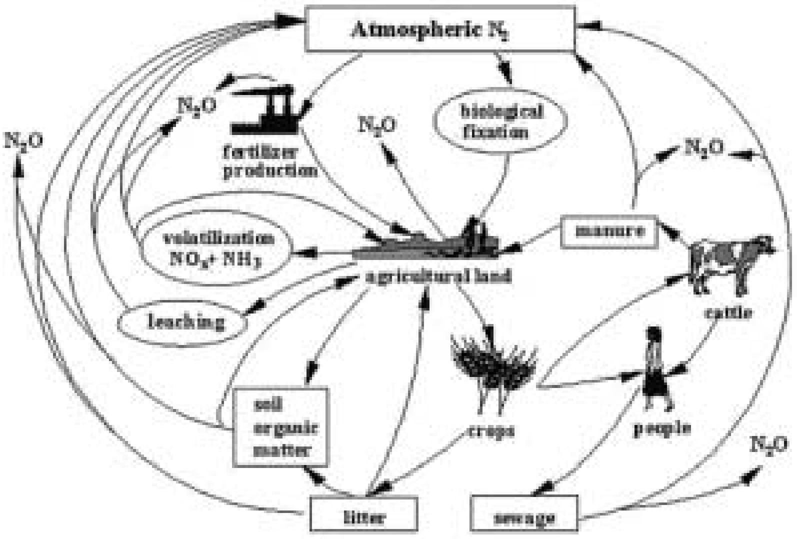
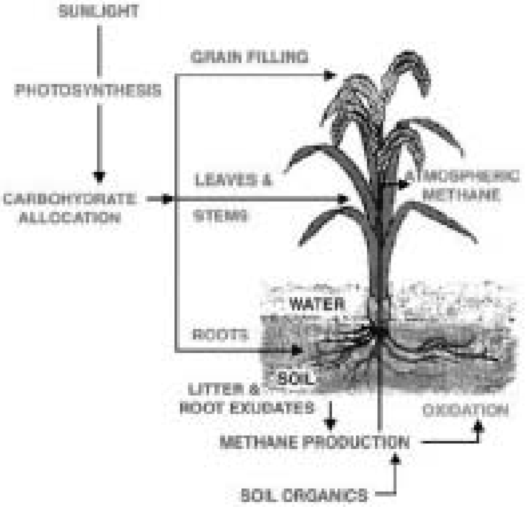


Figure 1.3c N_2O production in agriculture (from: http://www.igac.noaa.gov/newsletter/highlights/1998/n2o.php)



Methane is formed under anaerobic conditions at the end of the reduction chain when all other electron acceptors such as, for example nitrate and sulphate, have been used. Methane emissions from freely drained cropland soils are, therefore, negligible. In fact, aerobic cropland soils tend to oxidise methane, but less so than uncultivated soils (Goulding *et al.*, 1995; Willison *et al.*, 1995) with the oxidising capacity for forest, grassland and cropland soils showing the trend forests>grasslands>crops = 10 > 6 > 3 kg CH_4 ha^{-1} yr^{-1} respectively (Boeckx & Van Cleemput, 2001). The only sustained emissions of methane from European cropland soils occurs under irrigated rice production. The area of rice grown in Europe is, however, small and occurs mainly in southern Europe.

Figure 1.3d Methane production under rice (from:



When assessing the impact of land use on changes in greenhouse gas emissions, it is important to consider the impacts on all greenhouse gases (Robertson et al., 2000; Smith et al., 2001). Further, while animal production is not covered by this report, it should be emphasized that changes in manure management, such as the proportion deposited during grazing, may also influence the GHG balance of land use strategies. In order to assess the GHGs together, N_2O and CH_4 emissions are often expressed in terms of CO_2 or CO_2-carbon equivalents, which is possible because the radiative forcing of nitrous oxide, methane and carbon dioxide, can be integrated over different timescales and compared to that for CO_2. This measure is called the Global Warming Potential (GWP). For example, over the 100-year timescale, one unit of nitrous oxide has the same global warming potential as 296 units of carbon dioxide, whereas, on a kilogram for kilogram basis, one unit of methane has the same GWP as 23 units of carbon dioxide (IPCC, 2001a).

1.4 Greenhouse gas fluxes from European croplands

Croplands (i.e. lands used for the production of arable crops) cover about 1/3 of Europe's land surface and are estimated to be the largest biospheric source of carbon loss to the atmosphere in Europe each year. The cropland estimate is the most uncertain among all land-use types (Janssens *et al.*, 2003). It is estimated that croplands (in Europe as far east as the Urals) lose 300 Mt C y^{-1} (Janssens et al., 2003), with the mean for the European Union (EU-15) of 78 (SD: 37) Mt C y^{-1} (Vleeshouwers & Verhagen, 2002). National estimates of cropland CO2 fluxes for some EU countries are of similar magnitude on a per area basis (Sleutel *et al.*, 2003) but other estimates were lower (Dersch & Boehm, 1997). The size of the estimated per- hectare carbon flux from cropland is similar to the flux measured when converting grassland to tilled cropland (as calculated from figures in Johnston, 1973). Since this is an extreme land-use change, it suggests that current estimates may be too high. Indeed, Janssens *et al.* (2004) reduced their estimate for geographical Europe to 120 Mt C y^{-1}. The EU-15 estimates for the CO_2 cropland emissions (~78 Mt C y^{-1}) are of the same order of magnitude as the reported emissions of N_2O from agricultural soil (~60 Mt C-eq. in 2000) and CH_4 from agriculture (~50 Mt C-eq. in 2000; see section 4).

The values for CO_2 flux suggest that cropland soil carbon stocks are continuing to decline, perhaps as a result of recent (decadal) land-use change. However, figures for net changes in land use during the past 20-30 years do not suggest a large scale conversion to cropland from other land uses but may not show all areas that have undergone a change as they report only net changes. An alternative reason for the high C loss from agricultural soils in some regions may be changes of agricultural management (e.g. manure use) over recent decades (Sleutel *et al.*, 2003). The figures for cropland soil carbon loss are highly uncertain (Janssens *et al.*, 2003) and there is clearly scope to reduce the uncertainty surrounding these estimates.

• 2. Agricultural practices leading to GHG emissions

In Europe, most soils are out of equilibrium as they have been affected by past land use / management practices. Management practices affecting GHG emissions from agricultural areas include changes between arable and grassland, grassland and forest, etc., cropland management such as tillage and rotations, fertiliser use, legumes, the type of fertiliser applied, the farm management pattern, grassland management such as ley systems (cut or grazed), water management etc. and the use of non-built urban and suburban land (parks and gardens).

Cropland practices that influence GHG emissions from agriculture are discussed in detail in section 5. The FAO states that climate, soil fertility (C content) and fertilisation are the most important drivers for N_2O emission from agricultural soils. In cropping management, both crop type and soil wetness status are major influences on N_2O emission (Lilly *et al.*, 2002) and on CH_4 exchange (Smith *et al.*, 2000). These factors also influence the effect of a given cropland practice (Table 2.1) on non-CO_2 greenhouse gas emissions. For example, crop residues applied to a short-term grazed ley cannot be incorporated as they would be on land ploughed for arable cropping. Also minimum tillage of cereals into grassland rather than into previously ploughed land leaves a thatch of organic material near the surface. The different practices in each case result in a different mix and intensity of greenhouse gas fluxes. For these reasons, the emissions possible, even from well-researched practices, cover a wide range. One such practice is mineral fertiliser application where a typical soil N_2O emission from a ley is 2-10 kg/ha/year, but Dobbie & Smith (2003) reported up to 28 kg/ha/year at a site in Wales. Gas fluxes from less well-researched practices are even more uncertain, partly because of the paucity of data available and because the N and C composition of the manures and their evenness of spreading are so variable. Up to 23 kg/ha N_2O have been measured after a single application of sewage sludge (Scott et al., 2000). Other cropping practices with great uncertainty are conservation tillage and organic farming. For example, no-tillage can give N_2O fluxes up to 4 times greater than under conventional tillage (Vinten *et al.*, 2002; Goossens *et al.*, 2001) whereas others report smaller differences between tillage treatments.

Fluxes of GHGs from animal management, principally CH_4, are a little better understood, but are a function of a range of interacting factors, making it difficult to estimate flux from a given land area (Chadwick *et al.*, 2000) or even per animal. Thus, for each cropping practice, we have defined in Table 2.1 the likely rankings of emissions of N_2O, CH_4 and NOx applicable to the land use practices in Table 2.2. For CH_4, the minus sign indicates atmospheric uptake and the plus sign indicates emission. NOx (NO and NO_2) emissions are included as these gases increase tropospheric ozone production, thereby reducing the tropospheric CH_4 sink, and are precursors of acid rainfall. For each practice in Table 2.2 we have allocated a ranking for each gas. Note that in Table 2.2 a ranking for the importance of each practice is also given for carbon sequestration. This is low (x), medium (xx) or high (xxx). The practices listed in Table 2.2 refer to the addition of amendments (e.g. fertiliser), soil management (e.g. tillage), stock and crop management and inappropriate management (e.g. compaction). The table does not include indirect emissions of gases from drainage water and fresh water.

Table 2.1 Probability rankings of emissions of non-CO_2 greenhouse gases used in Table 2.2.

Ranking	Nitrous oxide (N_2O), kg/ha/year	Methane (CH_4), kg/ha/year	NOx, kg/ha/year
x Unlikely to exceed	5	± 1	1
xx Unlikely to exceed	10	± 2	2
xxx Could exceed	10	± 2	2

Table 2.2. Table of fluxes (Note: ranking is applicable within rows)

Practices		N2O	CH4	NOx	C-seq.
Inorganic fertiliser	Application techniques (placement, timing) Type (through effect on ammonia emissions) Type and characteristics	xxx	x	xx	xx
	Application techniques - synchronisation/timing (e.g. split-application) - placement	xxx	0	xx	x
	Amount/rate of application	xxx	0	xx	xx
Organic fertiliser	Type - Farm yard manure, (flux dependent on degree of maturity/degradation, moisture content) - Liquid fertiliser/slurry (give higher N_2O fluxes than dried material.) - industrial waste - household waste - biogas residue (BR) - fermented manure	xxx	xx	xx	xxx
	Timing (less critical than for inorganic fertiliser)	xx	xx	x	0
	Application techniques Storage, processing, and handling (temperature, duration, capacity, cover, etc.); FYM > others; N_2O flux dependent on dimensions : CH_4 flux from storage depends on aeration stage and crusting; NOx emitted during composting – ammonia emissions.	xxx	xx	xxx	x
	Amount/rate of application	xxx	x	xx	xxx
Biological N fixation	(Mono cropping, legumes/grass mixture ratio, organic systems); most of the fluxes after ploughing; net effect is unknown)	xx	0	xx	x
Crop residue	(Important for C sequestration) ○ quality and size (C :N ratio, total N; narrow ratio increases flux of N_2O) ○ quantity (weight) ○ application/incorporation techniques (interaction with tillage; priming effect on soil N_2O flux mainly with incorporation)	xx	0	xx	xxx
Farming system & mgt.	Further research needed on the effects of extensive/intensive management and arable/livestock proportions)	?	?	?	?

Practices		N2O	CH4	NOx	C-seq.
Tillage	Important for C sequestration and interaction with soil physical condition ○ ploughing (dependent on the available N at the time of ploughing) ○ no tillage; reduces NO ○ conservation (reduced) tillage (probably intermediate)	xx	x	xx	xxx
Water management	Drainage, irrigation, flooding water buffers, etc. Carbon sequestration effects unknown	xxx	xxx	xx	?
Compaction status	○ inappropriate timing of field operations and use of over-sized equipment ○ poaching	xx	x	xx	0
Animal management	- ○ diet composition ○ level of intake ○ animal productivity/genetics ○ intensity of system of animal production ○ meat/milk production ○ housing system ○ storage capacity for manure ○ age of slaughtering	x	xxx	?	0
Grazing intensity	Including stock numbers and type of grass conservation	xxx	xxx	x	x
Local ammonia abatement		xx	0	x	0
Biomass burning and biomass production.		x	x	xxx	xx

The farm level integrates the effects of driving forces in the surrounding society with the physical, chemical and biological processes that determine greenhouse gas emissions (Table 2.3). The integrating factor is the farm management, which may have a range of objectives and which also influence carbon and nitrogen cycling, including emissions.

The farm level response to change and the resulting effects on emissions depend on farm type and geographical region, including the prevailing soil and climate conditions. For simplicity the following categories of farm types can be distinguished:

- Intensive livestock with ruminants (>1.5 LU/ha), with grazing
- Intensive livestock with ruminants (>1.5 LU/ha), without grazing
- Extensive livestock with ruminants (<1.5 LU/ha), with grazing
- Intensive livestock with pigs, poultry
- Arable systems, agricultural and horticultural crops
- Permanent crops (fruits, vineyards, olives)

The highest emissions of methane and nitrous oxide are typically seen from intensive ruminant livestock systems. The methane from enteric fermentation in the ruminants contributes greatly to this, even though intensive production with high proportion of concentrates in the feed tends to reduce the emissions per kg milk or meat produced. Indirect emissions of nitrous oxide from leached nitrogen and ammonia volatilization are often lower for grazing systems compared with housed systems, which also often involve other types of forage crops. Inclusion of grasslands, in particular permanent grasslands, will increase the soil carbon storage. Intensive livestock systems with pigs and poultry may also have high emissions of nitrous oxide, in particular from the fertiliser and manures being applied in the production of the feed for the animals. In addition the manure management systems in intensive pig production is often based on slurry, which can give high methane emissions during storage.

Arable systems often tend to deplete soil carbon over time due to frequent soil tillage and periods of bare soils. Many of the agricultural and horticultural crops also require high inputs of nitrogen in fertilisers or manure, which gives rise to nitrous oxide emissions both directly from the applied nitrogen and indirectly from losses by leaching and ammonia volatilisation. The smallest emissions are probably from permanent crops, where nitrogen inputs as well as losses are small. The effects on soil carbon in these systems will probably depend on the weed control in these crops, including the extent of tillage to control weeds.

Table 2.3 Drivers of change affecting agricultural production and greenhouse gas emissions.

Driving force	Pressure	Result	Effect on GHG emissions
Increasing population	Intensification		Increase
EU CAP, agricultural policy, WTO	Maintain income	Migration, increase farm size, reduce cost	Decrease for CH4 and N2O. C-storage??
Prosperity, consumer choice of food, food safety	Quality of produce, more diverse range of products, flexibility, higher meat consumption	Increasing local production, regionalised food production, need for and risk in specialisation	Depends
Other EU regulations, e.g., NEC directive (emission ceilings for ammonia and other pollutants), nitrate directive	decrease air and groundwater pollutants		Decrease N_2O as co-benefit (nitrate dir.); NEC: possibly increase direct N_2O from soils, decrease indirect N_2O emissions from agriculture
Other values (animal welfare, environment, landscape)	Negative image of agriculture, Diversification, Regulations	Fewer skilled farmers, changes in management systems	Depends
Other claims for land (urban, infrastructure, afforestation)	Intensification		Decrease
Climate change	Adaptation, extreme events, water resources	Land use change (northward shift), modification of environmental impacts of agriculture (SOM mineralisation), expand production areas for sensitive crops, regionally specific effects	Increase for CH4 and N2O (CO2-effect uncertain)
Need for clean water and environment	Restrictions on land use	Extensification regionally, higher resource use efficiencies	Decrease (some technologies may increase emissions)
Energy price (increase)	Produce energy, reduce energy cost (direct and indirect, non-factor input)	Reallocation of production, development of energy efficient technologies, bioenergy crops	Decrease
Labour and skill availability (lack of)	Negative image of agriculture	Fewer skilled farmers	Increase
Research and development	Increasing productivity, capital intensive agriculture		Depends on whether GHG is a driving force in R&D
Economic power of farms	Reduced capital	Less ability for actions, lower recourse use efficiency	Increase
Labour age structure	Aging of land labour	Less flexibility and adaptability	Increase

• 3. Methods for accounting for GHG emissions

The IPCC suggests default methods for estimating emissions of GHGs from agriculture and land-use change. Nitrous oxide and methane emissions are accounted for under the agricultural sector (Chapter 4 of the Revised 1996 IPCC guidelines for National Greenhouse Gas Inventories; IPCC, 1997) whereas carbon dioxide emissions are estimated in the land-use change sector (Chapter 5 of the Revised 1996 IPCC guidelines for National Greenhouse Gas Inventories; IPCC, 1997). Since field burning of agricultural residues is no longer permitted within the EU (though some still occurs in EU and new accession countries), these are not discussed here.

It should be stressed that the IPCC encourages individual countries to adopt own activity data and emission factors to the extent that such information is available and properly documented. To a large extent this occurs in practice. For example, a working group recently summarized the national adaptations of the IPCC default methodology used by the five Nordic countries (Denmark, Finland, Iceland, Norway and Sweden) for methane and nitrous oxide emissions from agriculture (Petersen et al., 2002). These adaptations resulted in deviations from the IPCC default estimate of –12 to +13% for methane, and of –38 to +10% for nitrous oxide. The IPCC default methods and emission factors are outlined in appendix 1.

Indirect CO_2 losses from dissolved organic carbon and from eroded material are not considered in the current IPCC method at present, but should be considered in the future.

3.1 Possibilities for improving methods to estimate GHG emissions in the future

A gap in our scientific knowledge concerns the fluxes that occur as a direct impact of a land use or management change. Instead of considering only the land use before and after a land-use or management change, more research is needed on the usual flush of (mostly) CO_2 resulting from the change itself and its duration. The transition from one usage of land to another will seriously disturb the approximate equilibrium situation which exists before the change and which will be established after some time, perhaps decades. There is scant knowledge about the causes of these enhanced fluxes, about their duration and the amounts of carbon and nitrogen lost. Long term monitoring sites with a reasonable frequency of measurements might help to assess the contribution of such a land use change to emissions.

There is scope within the current IPCC methodology to replace default emission factors and default methods with better regionally specific emission factors, where these are available, or more elaborate methodologies where these have been developed. Recent work has defined country specific values for the U.S. and found that the C sequestration rate for U.S. agricultural land was about half of the rate estimated using the default factors, primarily due to differences in the set-aside factor and the reference carbon stocks, which were computed from US data (Ogle *et al.*, 2003). It would be highly desirable to perform a similar analysis to produce regionally specific values for the EU.
Another option is to develop dynamic emission factors. The IPCC default methods for calculating emission factors are static, i.e. they are predominantly unaffected by soil type and climate (except for CO_2) and they are assumed to be linear, i.e. they occur at a constant rate over time. However, it is known that a change in land management practice causes a non-linear change over time. Soil organic carbon, for example, is not lost at a constant rate over a 20-year period, but is better represented by an exponential loss (or gain) either as single or as multiple pools with exponential decay of soil organic carbon, which can be modelled e.g. by a first order reaction rate. It would be possible to implement emission factors based on exponential equations, or more

complex models of decomposition. However, to do so, more information may be required about the soil type (such as clay content, which stabilises SOC) or climate (decomposition is sensitive to temperature and soil moisture). These factors might be available in climatological and soil databases, but another important factor will be land-use history, which will be far more difficult to estimate. Another point to note is that soil carbon gains and losses are not symmetrical: carbon is lost more quickly when grassland is ploughed to cropland, than it is gained when croplands are reseeded to grass. This also needs to be acknowledged in any revised methodology. Any new IPCC methodology would need to consider soil types, structures and soil C contents (prior to land use changes). Similar dynamic emission factors can be envisaged also for methane and nitrous oxide. Dobbie & Smith (2003) found that annual emission factors for N_2O varied greatly from year to year, even with similar management and that several years' data were needed to produce a robust emission factor. They also recommended that differences in emission factor between various types of crop should be taken into account when compiling N_2O inventories. Further, some effects of agricultural management (e.g. use of nitrification inhibitors) cannot be assessed by the IPCC method. Dynamic emission factors (which respond to climate, moisture interactions, soil type, crop type and land-use history) would provide a step closer to reality, but the quest for realism needs to be weighed against burgeoning data requirements.

Some suggestions have already been made for dynamic emission factors for nitrous oxide. Dynamic emission factors could be based upon simple (statistically derived) variables such as crop type, e.g. cereals, tuber crops, proportion of grass in the rotation, climate zone, precipitation in winter, temperature and soil type, or could be output from more complex, dynamic simulation models that include all of these interactions. Such an approach has been attempted in the USA by K. Paustian et al. (pers. comm. – some details in EPA, 2003). Drivers might differ according to different spatial areas, e.g. regional, continental, or national scales, or might be based on farm management types. However, data accessibility, consistency and availability need to be considered. A further consideration is how to ensure verifiability (see section 6).

Since there is scope within the current IPCC methodology to replace default emission factors and default methods it is possible to develop dynamic emission factors within the existing IPCC framework. However, with the IPCC methodologies being revised over the next 2-3 years, dynamic emission factors may appear in some sections as the new default methodologies. Research into emission factors should feed into a new IPCC emission factors database. This database will be the first step toward providing more meaningful emission factors for use in different parts of the world.

Process models (e.g. DNDC; Brown *et al.*, 2003) may play a role in better determining N_2O, CO_2 and CH_4 fluxes from soils. If such models are validated first against existing (country specific) emission data, they can be used to estimate country level inventories. The advantage of such an approach is that climate and management effects can be assessed. A similar approach has already been advocated in the Joint EMEP/CORINAIR Atmospheric Emission Inventory Guidebook (EMEP/CORINAIR, 2003). Such an approach has been applied in Belgium (P. Boeckx, pers. comm.) and the UK. Since one emission may be exchanged by another, e.g. methane in saturated soil systems may be replaced by nitrous oxide if such a soil is drained, and vice versa, both experiments and models should consider nitrous oxide, methane and carbon dioxide are together.

Meta-analyses of existing N_2O emission data can also be used to derive better country specific emission factors. In Belgium, statistical links between annual N_2O emissions reported in the literature and land use, seasonal climate, soil characteristics and

N fertilisation rates have been established in order to provide a simple model that allows the spatial variation in environmental conditions to be taken into account in national inventories. Distinct models were developed for croplands and grassland. Emissions from croplands are sensitive to the mean temperature of the coldest month, summer precipitation and temperature, clay fraction and N fertilisation rate. Emissions from grasslands are driven by N fertilisation and summer precipitation and temperature. These empirical models are capable of explaining 60 % of the variance of annual N_2O emissions from croplands and 52 % for grasslands (Roelandt *et al.* submitted).

Upscaling of N_2O fluxes using spatial information on soil wetness and land use types may provide good inventory information (Lilly *et al.*, 2003). The advantage of this approach is that areas of high emissions can be identified and application of mitigation strategies in these areas are likely to be most effective at reducing fluxes.

• 4. Estimates of GHG emissions from European agriculture

The most important sources of emissions from agriculture in Europe are methane from enteric fermentation from ruminants and pseudo-ruminants (i.e. cattle, sheep, goats, pigs, and horses; not considered in this cropland report), methane from manure management (not considered in this cropland report), nitrous oxide from agricultural soils and indirect emissions of nitrous oxide from N-use in agriculture. Indirect emissions are from polluted surface waters and from deposition of ammonia and nitrogen oxides onto soils. Carbon dioxide can be lost from cropland, but under improved management could be sequestered. Peat soils that have been drained for agriculture are a large source of carbon dioxide because of top-soil mineralisation. In the Western part of the Netherlands, for example, in some places 2 meters of peat has disappeared since the first peat drainage works around in around 1200 AD. A number of studies have been published in which nitrous oxide emissions from agriculture and the methane oxidation capacity of soils have been estimated in Europe (Boeckx & Van Cleemput, 2001) and in individual countries (e.g. Boeckx *et al.*, 2001).

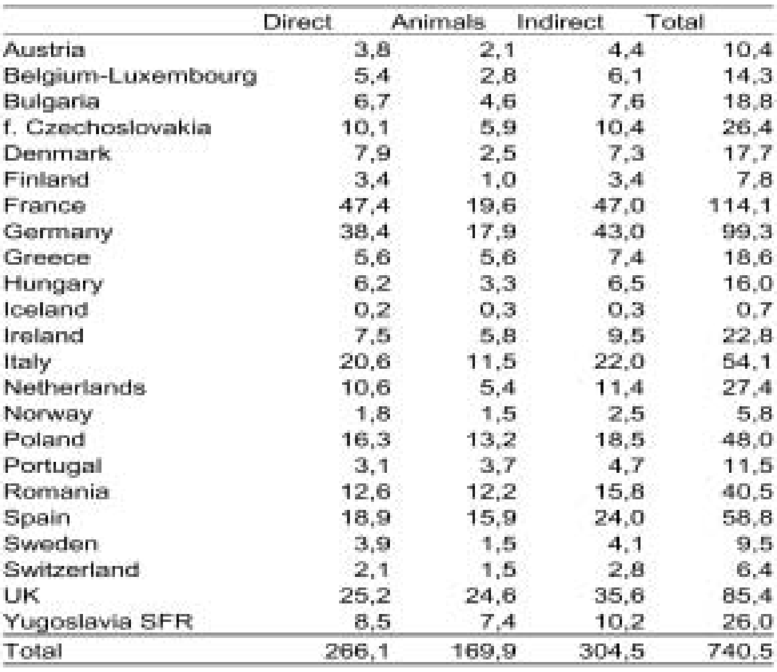
The IPCC methodology to estimate emissions of nitrous oxide, methane and carbon dioxide from agriculture are described in appendix 1. Here some results are given of the emission estimates using default IPCC methodology and FAO statistics. The results are compared to the official estimates from Parties to the UNFCCC.

4.1 Nitrous oxide

4.1.1 1990 emissions of nitrous oxide

The official estimates for nitrous oxide are given in full molecular weight of N_2O and the IPCC estimates are given in million kg N_2O-N (conversion factor from N to N_2O = 1.57). Tables 4.1.1a and 4.1.1b give estimates of 1990 nitrous oxide emissions calculated using the IPCC methodology. The total European emission is ~740 Million kg N yr^{-1} with indirect emissions larger than direct emissions and emissions from animals.

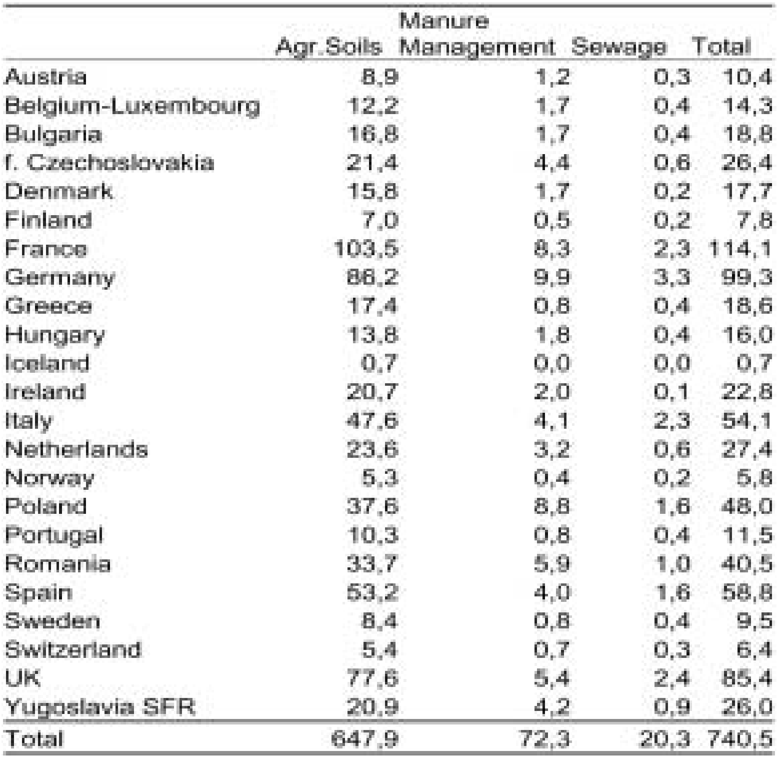
Table 4.1.1a Nitrous oxide emissions in Europe in 1990 (Million kg N yr^{-1}). Calculated using IPCC methodology and default emission factors and FAO data. Source: Kroeze and Mosier (2000)



	Direct	Animals	Indirect	Total
Austria	3,8	2,1	4,4	10,4
Belgium-Luxembourg	5,4	2,8	6,1	14,3
Bulgaria	6,7	4,6	7,6	18,8
f. Czechoslovakia	10,1	5,9	10,4	26,4
Denmark	7,9	2,5	7,3	17,7
Finland	3,4	1,0	3,4	7,8
France	47,4	19,6	47,0	114,1
Germany	38,4	17,9	43,0	99,3
Greece	5,6	5,6	7,4	18,6
Hungary	6,2	3,3	6,5	16,0
Iceland	0,2	0,3	0,3	0,7
Ireland	7,5	5,8	9,5	22,8
Italy	20,6	11,5	22,0	54,1
Netherlands	10,6	5,4	11,4	27,4
Norway	1,8	1,5	2,5	5,8
Poland	16,3	13,2	18,5	48,0
Portugal	3,1	3,7	4,7	11,5
Romania	12,6	12,2	15,8	40,5
Spain	18,9	15,9	24,0	58,8
Sweden	3,9	1,5	4,1	9,5
Switzerland	2,1	1,5	2,8	6,4
UK	25,2	24,6	35,6	85,4
Yugoslavia SFR	8,5	7,4	10,2	26,0
Total	266,1	169,9	304,5	740,5

Table 4.1.1b shows that among the sectors contributing to nitrous oxide emissions, agricultural soils account for the great majority (>85%).

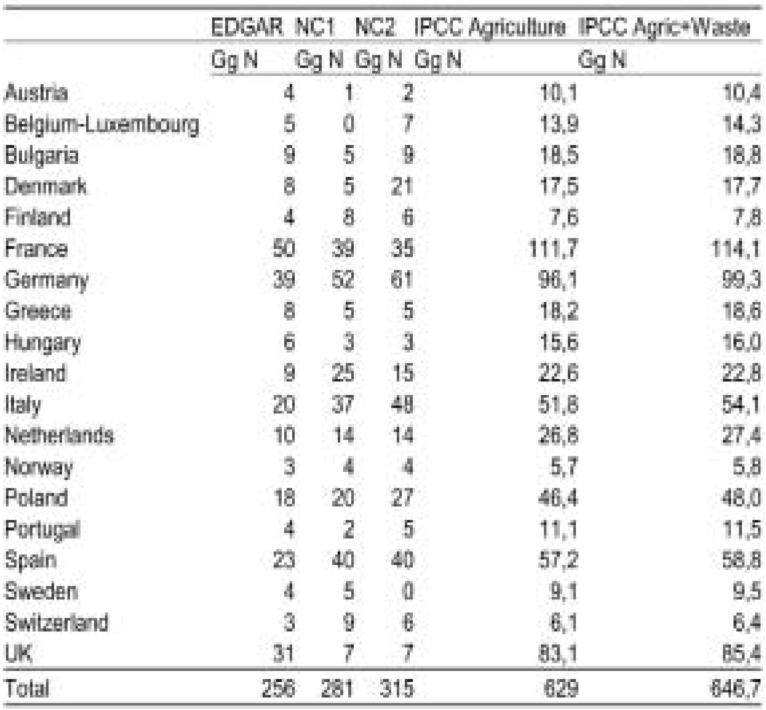
Table 4.1.1.b Nitrous oxide emissions in 1990 in Europe (Million kg N yr-1). Calculated with IPCC methodology and reported in IPCC categories. Source: Kroeze and Mosier, 2000



	Agr.Soils	Manure Management	Sewage	Total
Austria	8,9	1,2	0,3	10,4
Belgium-Luxembourg	12,2	1,7	0,4	14,3
Bulgaria	16,8	1,7	0,4	18,8
f. Czechoslovakia	21,4	4,4	0,6	26,4
Denmark	15,8	1,7	0,2	17,7
Finland	7,0	0,5	0,2	7,8
France	103,5	8,3	2,3	114,1
Germany	86,2	9,9	3,3	99,3
Greece	17,4	0,8	0,4	18,6
Hungary	13,8	1,8	0,4	16,0
Iceland	0,7	0,0	0,0	0,7
Ireland	20,7	2,0	0,1	22,8
Italy	47,6	4,1	2,3	54,1
Netherlands	23,6	3,2	0,6	27,4
Norway	5,3	0,4	0,2	5,8
Poland	37,6	8,8	1,6	48,0
Portugal	10,3	0,8	0,4	11,5
Romania	33,7	5,9	1,0	40,5
Spain	53,2	4,0	1,6	58,8
Sweden	8,4	0,8	0,4	9,5
Switzerland	5,4	0,7	0,3	6,4
UK	77,6	5,4	2,4	85,4
Yugoslavia SFR	20,9	4,2	0,9	26,0
Total	647,9	72,3	20,3	740,5

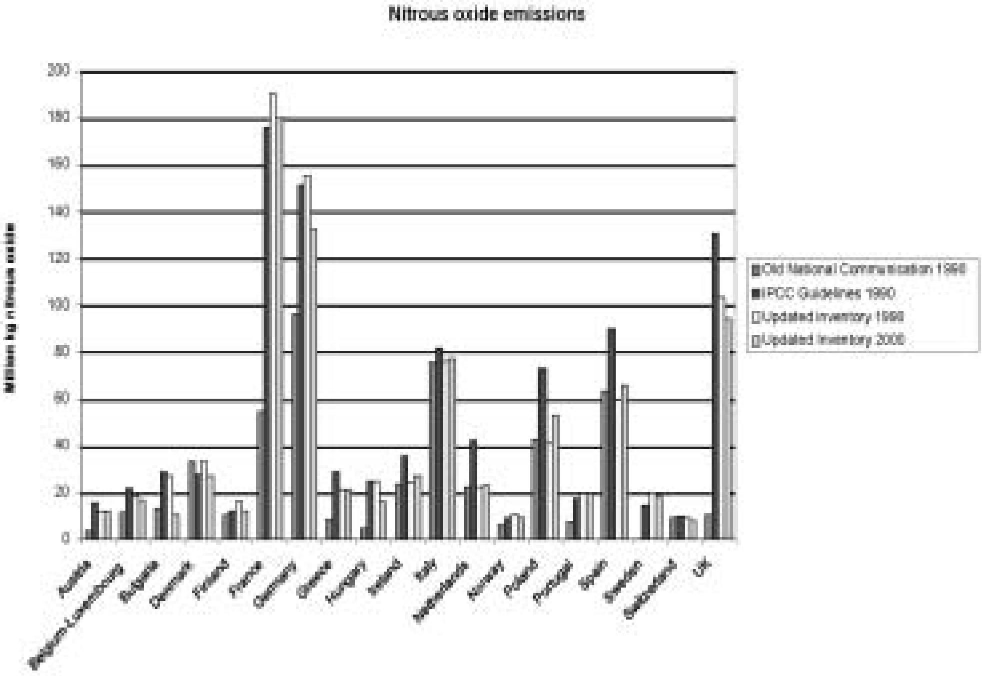
Table 4.1.1c compares the 1990 emissions taken from the Emissions Database for Global Atmospheric Research (EDGAR, Olivier 2002) with the first and second national communication of Parties to the Climate Convention. The EDGAR estimates generally correspond well with the figures in the national communications, whereas the estimates using the IPCC methodology suggest emissions approaching two times the reported values for Europe as a whole, though for some countries, the reported values are closer to estimates using the IPCC methodology, e.g. Ireland, Italy, Spain, Switzerland, Norway (Figure 4.1.1). Since many EU countries use more sophisticated methods for estimating emissions than the IPCC default methods, the national communications should be regarded as more reliable than methods using the IPCC defaults.

Table 4.1.1c Comparison of estimates of nitrous oxide emissions from 1990 (Million kg [Gg] N) as taken from the Emissions Database for Global Atmospheric Research (EDGAR, Olivier 2002), from the first and second national communication of Parties to the Climate Convention and calculated with the IPCC methodology. Source: Van Amstel et al., 1999 and UNFCCC



	EDGAR	NC1	NC2	IPCC Agriculture	IPCC Agric+Waste
	Gg N	Gg N	Gg N	Gg N	Gg N
Austria	4	1	2	10,1	10,4
Belgium-Luxembourg	5	0	7	13,9	14,3
Bulgaria	9	5	9	18,5	18,8
Denmark	8	5	21	17,5	17,7
Finland	4	8	6	7,6	7,8
France	50	39	35	111,7	114,1
Germany	39	52	61	96,1	99,3
Greece	8	5	5	18,2	18,6
Hungary	6	3	3	15,6	16,0
Ireland	9	25	15	22,6	22,8
Italy	20	37	48	51,8	54,1
Netherlands	10	14	14	26,8	27,4
Norway	3	4	4	5,7	5,8
Poland	18	20	27	46,4	48,0
Portugal	4	2	5	11,1	11,5
Spain	23	40	40	57,2	58,8
Sweden	4	5	0	9,1	9,5
Switzerland	3	9	6	6,1	6,4
UK	31	7	7	83,1	85,4
Total	256	281	315	629	646,7

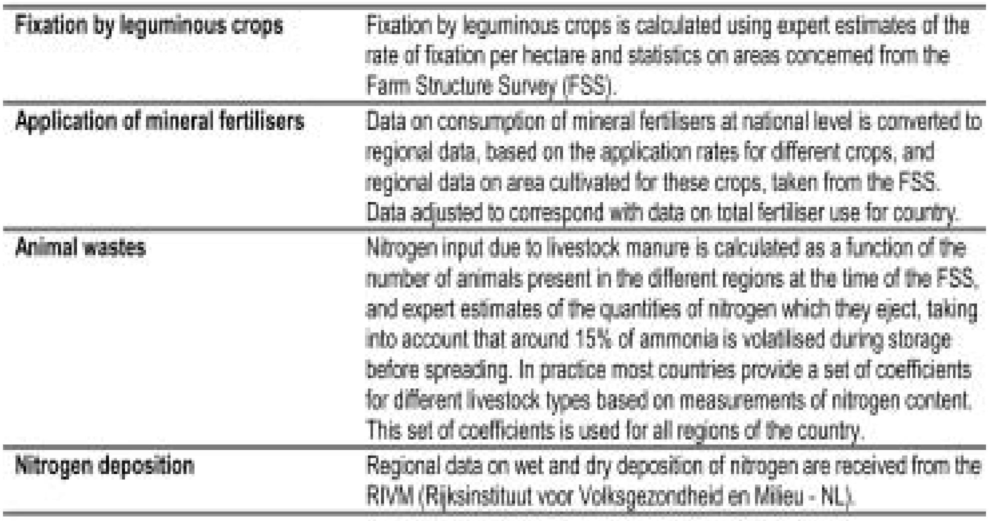
Figure 4.1.1 Comparison of nitrous oxide emission estimates from national inventories and IPCC Guidelines (Source: Van Amstel, 2003)



4.1.2 2000 emissions of nitrous oxide

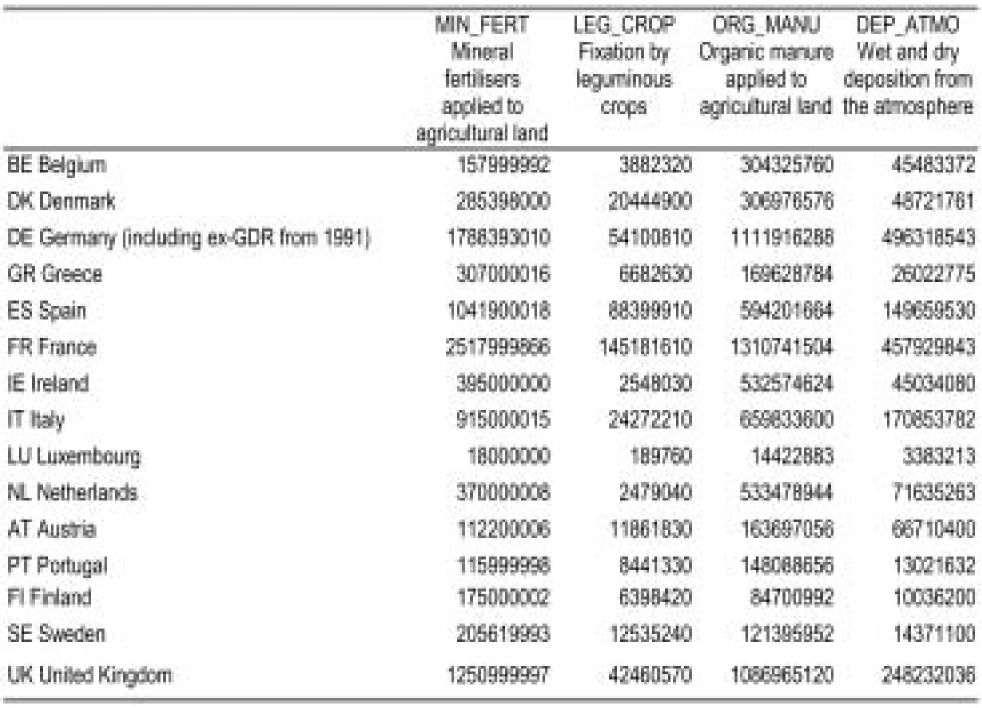
In the NewCronos Database, under the Theme 8 “Environment and Energy” – Domaine “Milieu” - Collection “Agriculture” the nitrogen balance at the NUTS 2 level is tabulated: http://europa.eu.int/newcronos/suite/nc_data/info/notmeth/en/theme8/milieu/agri/agri.htm?action=notmeth. It contains information on the input of nitrogen by addition of synthetic fertiliser, organic fertiliser, fixation by leguminous crops, and wet and dry deposition. The origin of the data is explained in the explanatory section of the collection and is reproduced (for nitrogen input data) in Table 4.1.2a. Data are available for the years 1993, 1995, and 1997. The data for 1997 are shown in 4.1.2b.

Table 4.1.2a Explanatory text for the information on N input (N balance collection of NewCronos, EUROSTAT)



Fixation by leguminous crops	Fixation by leguminous crops is calculated using expert estimates of the rate of fixation per hectare and statistics on areas concerned from the Farm Structure Survey (FSS).
Application of mineral fertilisers	Data on consumption of mineral fertilisers at national level is converted to regional data, based on the application rates for different crops, and regional data on area cultivated for these crops, taken from the FSS. Data adjusted to correspond with data on total fertiliser use for country.
Animal wastes	Nitrogen input due to livestock manure is calculated as a function of the number of animals present in the different regions at the time of the FSS, and expert estimates of the quantities of nitrogen which they eject, taking into account that around 15% of ammonia is volatilised during storage before spreading. In practice most countries provide a set of coefficients for different livestock types based on measurements of nitrogen content. This set of coefficients is used for all regions of the country.
Nitrogen deposition	Regional data on wet and dry deposition of nitrogen are received from the RIVM (Rijksinstituut voor Volksgezondheid en Milieu - NL).

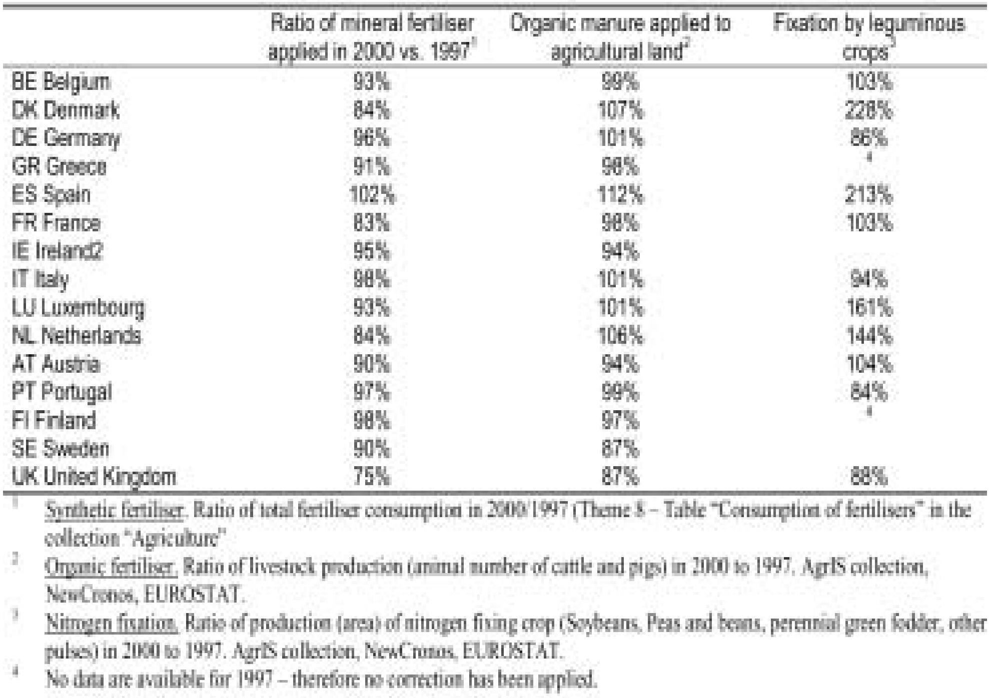
Table 4.1.2b Nitrogen input in 1997 for EU-15 countries (nitrogen balance collection of NewCronos, EUROSTAT). Values in kg nitrogen.



	MIN_FERT Mineral fertilisers applied to agricultural land	LEG_CROP Fixation by leguminous crops	ORG_MANU Organic manure applied to agricultural land	DEP_ATMO Wet and dry deposition from the atmosphere
BE Belgium	157999992	3882320	304325760	45483372
DK Denmark	285398000	20444900	306976576	48721761
DE Germany (including ex-GDR from 1991)	1788393010	54100810	1111916288	496318543
GR Greece	307000016	6682630	169628784	26022775
ES Spain	1041900018	88399910	594201664	149659530
FR France	2517999866	145181610	1310741504	457929843
IE Ireland	395000000	2548030	532574624	45034080
IT Italy	915000015	24272210	659833600	170853782
LU Luxembourg	18000000	189760	14422883	3383213
NL Netherlands	370000008	2479040	533478944	71635263
AT Austria	112200006	11861830	163697056	66710400
PT Portugal	115999998	8441330	148088656	13021632
FI Finland	175000002	6398420	84700992	10036200
SE Sweden	205619993	12535240	121385952	14371100
UK United Kingdom	1250999997	42460570	1086965120	248232036

Here we estimate N_2O emissions from soils of the year 2000. Therefore, the data are extrapolated to the year 2000 using the correction factors in Table 4.1.2c.

Table 4.1.2c Correction factors to extrapolate the information on nitrogen input to agricultural soils from the year 1997 to 2000.



	Ratio of mineral fertiliser applied in 2000 vs. 1997[1]	Organic manure applied to agricultural land[2]	Fixation by leguminous crops[3]
BE Belgium	93%	99%	103%
DK Denmark	84%	107%	228%
DE Germany	96%	101%	86%
GR Greece	91%	98%	[4]
ES Spain	102%	112%	213%
FR France	83%	98%	103%
IE Ireland2	95%	94%	
IT Italy	98%	101%	94%
LU Luxembourg	93%	101%	161%
NL Netherlands	84%	106%	144%
AT Austria	90%	94%	104%
PT Portugal	97%	99%	84%
FI Finland	98%	97%	[4]
SE Sweden	90%	87%	
UK United Kingdom	75%	87%	88%

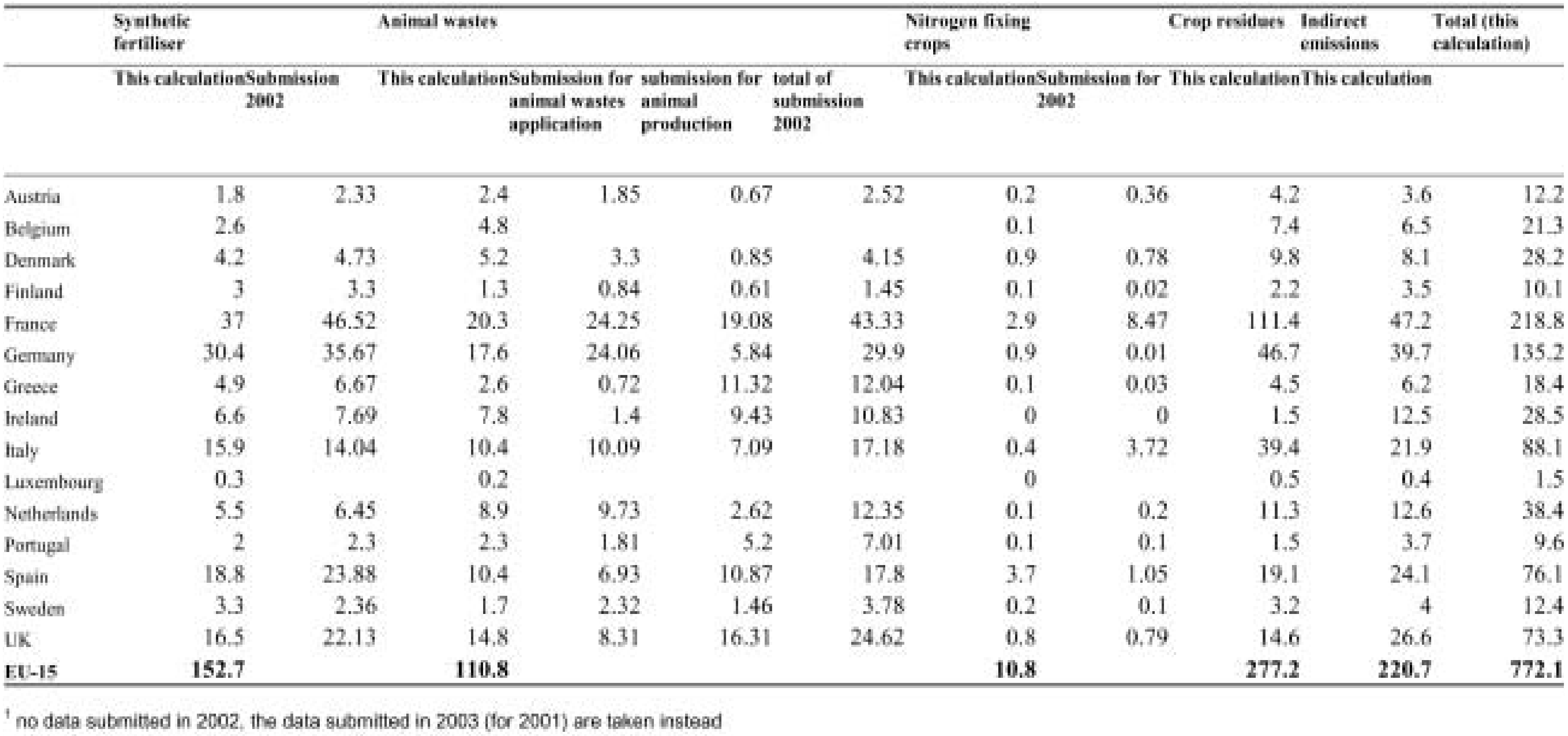
[1] Synthetic fertiliser. Ratio of total fertiliser consumption in 2000/1997 (Theme 8 – Table "Consumption of fertilisers" in the collection "Agriculture"

[2] Organic fertiliser. Ratio of livestock production (animal number of cattle and pigs) in 2000 to 1997. AgrIS collection, NewCronos, EUROSTAT.

[3] Nitrogen fixation. Ratio of production (area) of nitrogen fixing crop (Soybeans, Peas and beans, perennial green fodder, other pulses) in 2000 to 1997. AgrIS collection, NewCronos, EUROSTAT.

[4] No data are available for 1997 – therefore no correction has been applied.

Table 4.1.2d Comparison of N_2O emissions in 2000 from the application of synthetic fertiliser, the production of animal wastes, and nitrogen fixing crops, calculated using data from EUROSTAT and submitted to UNFCCC in 2002.



	Synthetic fertiliser		Animal wastes				Nitrogen fixing crops		Crop residues	Indirect emissions	Total (this calculation)
	This calculation	Submission 2002	This calculation	Submission for animal wastes application	submission for animal production	total of submission 2002	This calculation	Submission for 2002	This calculation	This calculation	
Austria	1.8	2.33	2.4	1.85	0.67	2.52	0.2	0.36	4.2	3.6	12.2
Belgium	2.6		4.8				0.1		7.4	6.5	21.3
Denmark	4.2	4.73	5.2	3.3	0.85	4.15	0.9	0.78	9.8	8.1	28.2
Finland	3	3.3	1.3	0.84	0.61	1.45	0.1	0.02	2.2	3.5	10.1
France	37	46.52	20.3	24.25	19.08	43.33	2.9	8.47	111.4	47.2	218.8
Germany	30.4	35.67	17.6	24.06	5.84	29.9	0.9	0.01	46.7	39.7	135.2
Greece	4.9	6.67	2.6	0.72	11.32	12.04	0.1	0.03	4.5	6.2	18.4
Ireland	6.6	7.69	7.8	1.4	9.43	10.83	0	0	1.5	12.5	28.5
Italy	15.9	14.04	10.4	10.09	7.09	17.18	0.4	3.72	39.4	21.9	88.1
Luxembourg	0.3		0.2				0		0.5	0.4	1.5
Netherlands	5.5	6.45	8.9	9.73	2.62	12.35	0.1	0.2	11.3	12.6	38.4
Portugal	2	2.3	2.3	1.81	5.2	7.01	0.1	0.1	1.5	3.7	9.6
Spain	18.8	23.88	10.4	6.93	10.87	17.8	3.7	1.05	19.1	24.1	76.1
Sweden	3.3	2.36	1.7	2.32	1.46	3.78	0.2	0.1	3.2	4	12.4
UK	16.5	22.13	14.8	8.31	16.31	24.62	0.8	0.79	14.6	26.6	73.3
EU-15	**152.7**		**110.8**				**10.8**		**277.2**	**220.7**	**772.1**

[1] no data submitted in 2002, the data submitted in 2003 (for 2001) are taken instead

The resulting N_2O emissions from synthetic fertiliser, animal excretions applied to soil or excreted during grazing and nitrogen fixation are shown in Table 4.1.2d. The data compare generally well with largest differences for the emissions calculated or submitted for nitrogen fixing crops. The emissions from animal wastes are calculated without differentiation between waste produced in animal houses or during grazing, and have therefore to be compared with the sum of the values submitted for the emissions for animal wastes application and animal production.

Additionally, data for crop residues are needed to be able to apply the IPCC methodology. The data are taken from the AgrIS (Agricultural Information System) collection, distinguishing between nitrogen fixing crops and non-nitrogen fixing crops. The emissions of nitrous oxide are calculated applying the IPCC default methodology (Tier 1a) for N_2O emissions from crop residues. Deviations between these calculated data and the values submitted in 2002 are very large of up to one order of magnitude, due to differences in the crop statistics and in the methodologies used (Table 4.1.2e). Generally, the use of Tier 1b methodology as proposed in the Good Practice Guidelines yield lower N_2O emissions by up to a factor of two.

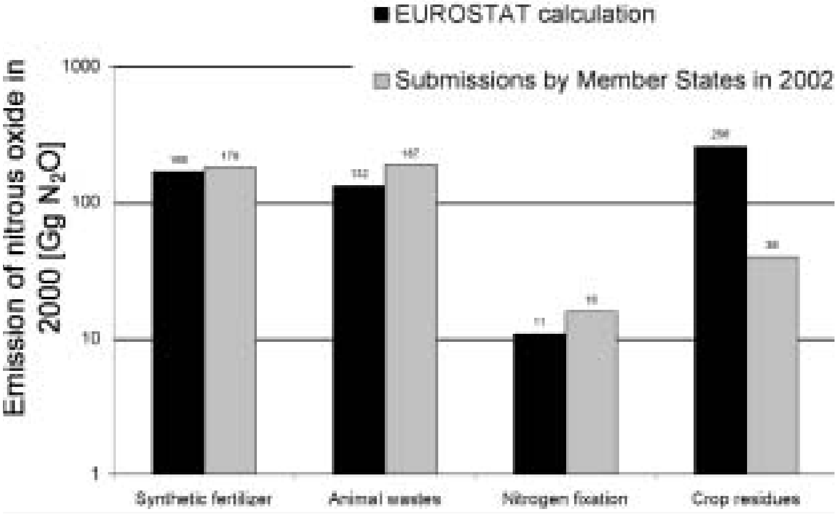
Table 4.1.2e N_2O emissions from crop residues in 2000 as calculated from EUROSTAT data and as submitted to UNFCCC (2002 submissions).

	Non N-fixing crops	N-fixing crops	N2O emissions	N2O emissions 2002 submissions
	[1000 t]	[1000 t]	[Gg N2O]	[Gg N2O]
BE Belgium	20610	1086	7.4	
DK Denmark	24741	2699	9.8	7.03
DE Germany 1	143870	68	46.7	3.82
GR Greece	13686	90	4.5	1.81
ES Spain	45426	6777	19.1	1.91
FR France	291406	28174	111.4	10.08
IE Ireland 1	4740	0	1.5	0.38
IT Italy	101918	9762	39.4	2.83
LU Luxembourg	1454	113	0.5	
NL Netherlands	34716	90	11.3	
AT Austria 1	11750	538	4.2	0.49
PT Portugal	4621	25	1.5	0.57
FI Finland	6040	310	2.2	0.83
SE Sweden	9794	0	3.2	1.32
UK United Kingdom	44494	216	14.6	8.77

1 no data submitted in 2002, the data submitted in 2003 (for 2001) are taken instead

A comparison of nitrous oxide emissions from all sources considered here is given in Figure 4.1.2.

Figure 4.1.2 Comparison, shown on a logarithmic scale, of soil N_2O emissions from synthetic fertiliser, animal wastes, nitrogen fixation and crop residues in 2000 (EU-15) as calculated using data available at Eurostat and submitted by the member states. Note: The values calculated for Belgium and Luxembourg are excluded from the plot because no disaggregated numbers have been submitted. The column for crop residues also excludes the values for the Netherlands and Ireland.



In table 4.1.2f the total nitrous oxide emissions from agriculture in Europe for 1990 and 2000 are compared, according to the official country submissions of the 15 EU parties to the UNFCCC. The total nitrous oxide emission is calculated from synthetic fertilizer application, manure application, fixation by leguminous crops, crop residues and histosols. Emissions in 1990 and 2000 remain broadly similar among countries showing a slight reduction (~5% or 40 Million kg N_2O yr^{-1}).

Table 4.1.2f N2O from agriculture in Europe in 1990 and 2000 (Million kg N_2O yr^{-1})

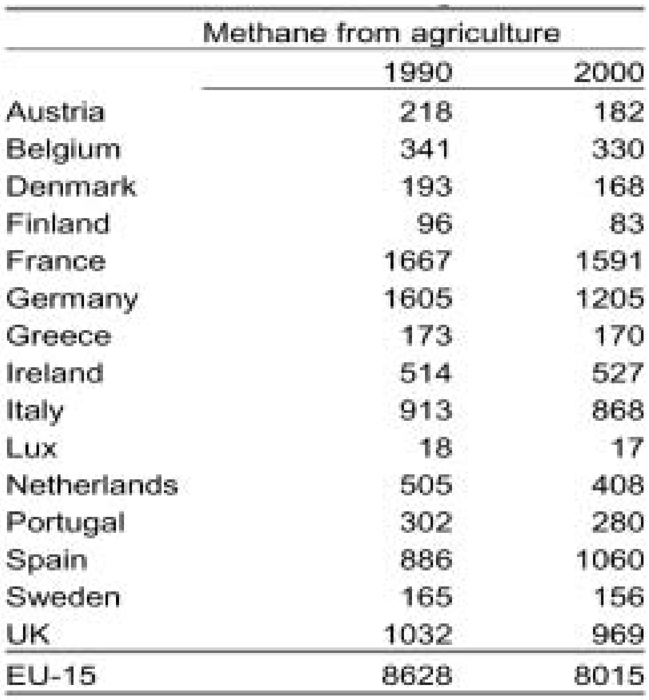
	Nitrous oxide from agriculture	
	1990	2000
Austria	3,31	3,19
Belgium	21,97	21,92
Denmark	33,09	26,75
Finland	15,89	12,57
France	177,21	172,28
Germany	157,09	132,87
Greece	22,01	21,47
Ireland	23,22	23,7
Italy	78,02	78,75
Lux	0,47	
Netherlands	22,11	24,34
Portugal	19,21	18,97
Spain	57,33	65,5
Sweden	14,58	13,51
UK	103,05	91,17
EU-15	748,21	707,01

In terms of CO_2–C equivalents, the total EU-15 nitrous oxide emissions for 1990 and 2000 were 60 and 57 Tg, respectively.

4.2 Methane (1990 and 2000 emissions)

In the following table the total methane emission estimates are given for 1990 and 2000 from the UNFCCC database. These estimates are based on the official country submissions. For most countries, methane emissions decreased slightly between 1990 and 2000 with an overall reduction of around 7% or 600 Million kg CH_4 yr^{-1}. In terms of CO_2–C equivalents, the total EU-15 methane emissions for 1990 and 2000 were 54 and 50 Tg, respectively.

Table 4.2a Methane from agriculture in Europe in 1990 and 2000 (Million kg CH_4/yr)

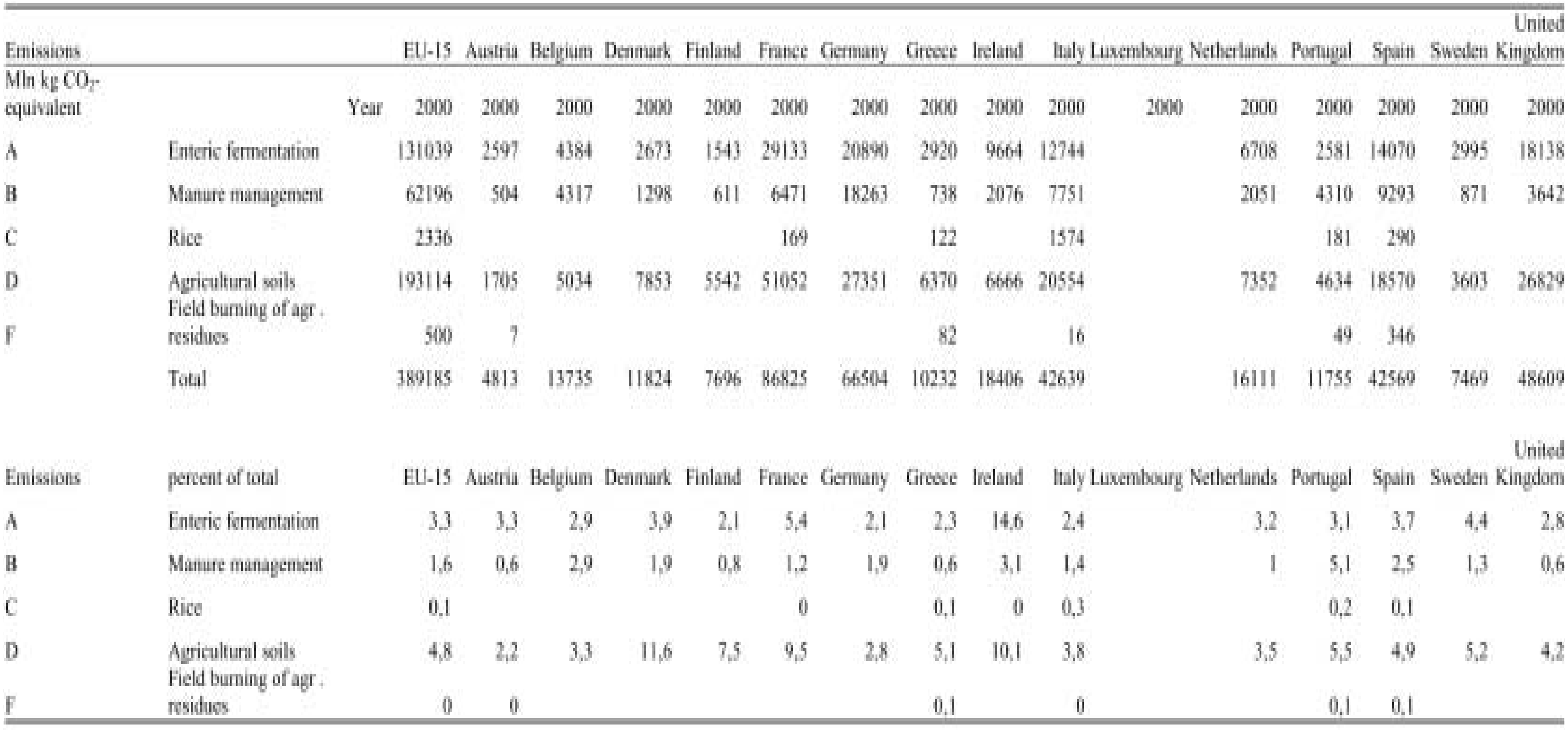


	Methane from agriculture	
	1990	2000
Austria	218	182
Belgium	341	330
Denmark	193	168
Finland	96	83
France	1667	1591
Germany	1605	1205
Greece	173	170
Ireland	514	527
Italy	913	868
Lux	18	17
Netherlands	505	408
Portugal	302	280
Spain	886	1060
Sweden	165	156
UK	1032	969
EU-15	8628	8015

4.3 Overall estimates for nitrous oxide and methane emissions in Europe

In table 4.3a and figure 4.3, the total emissions from agriculture are given as estimated by the EU-15 parties to the Climate Convention. The estimates in European countries are based on the IPCC methodology and country specific estimates. UNFCCC publishes yearly overviews based on the latest information by the parties.

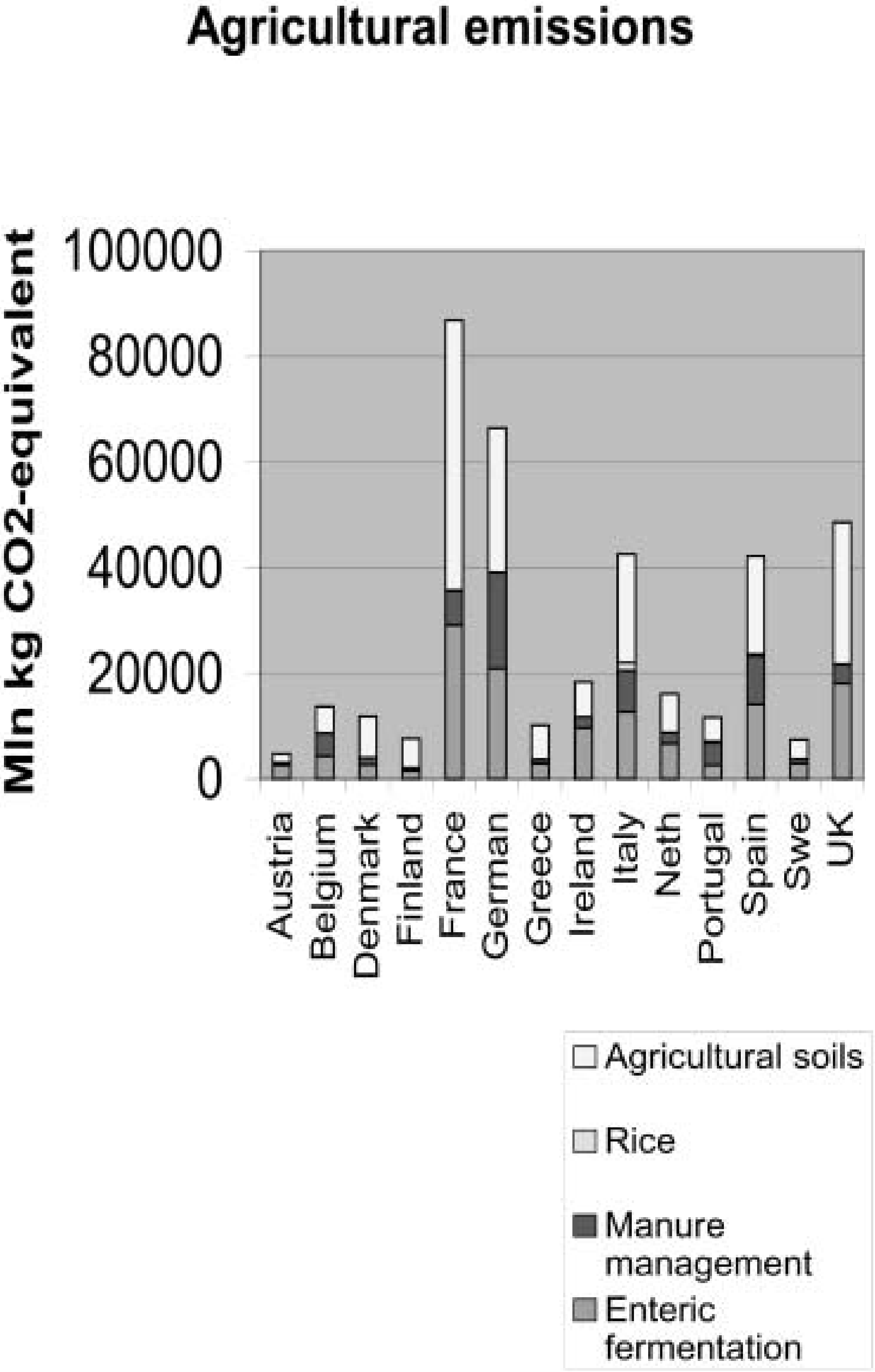
Table 4.3a Emissions of methane and nitrous oxide from agriculture in 2000 (Million kg CO2 equivalent). Calculated by Parties to the Climate Convention



Emissions			EU-15	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxembourg	Netherlands	Portugal	Spain	Sweden	United Kingdom
Mln kg CO_2-equivalent		Year	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
A	Enteric fermentation		131039	2597	4384	2673	1543	29133	20890	2920	9664	12744		6708	2581	14070	2995	18138
B	Manure management		62196	504	4317	1298	611	6471	18263	738	2076	7751		2051	4310	9293	871	3642
C	Rice		2336					169		122		1574			181	290		
D	Agricultural soils		193114	1705	5034	7853	5542	51052	27351	6370	6666	20554		7352	4634	18570	3603	26829
F	Field burning of agr . residues		500	7						82		16			49	346		
	Total		389185	4813	13735	11824	7696	86825	66504	10232	18406	42639		16111	11755	42569	7469	48609

Emissions	percent of total	EU-15	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxembourg	Netherlands	Portugal	Spain	Sweden	United Kingdom
A	Enteric fermentation	3,3	3,3	2,9	3,9	2,1	5,4	2,1	2,3	14,6	2,4		3,2	3,1	3,7	4,4	2,8
B	Manure management	1,6	0,6	2,9	1,9	0,8	1,2	1,9	0,6	3,1	1,4		1	5,1	2,5	1,3	0,6
C	Rice	0,1					0		0,1	0	0,3			0,2	0,1		
D	Agricultural soils	4,8	2,2	3,3	11,6	7,5	9,5	2,8	5,1	10,1	3,8		3,5	5,5	4,9	5,2	4,2
F	Field burning of agr . residues	0	0						0,1		0			0,1	0,1		

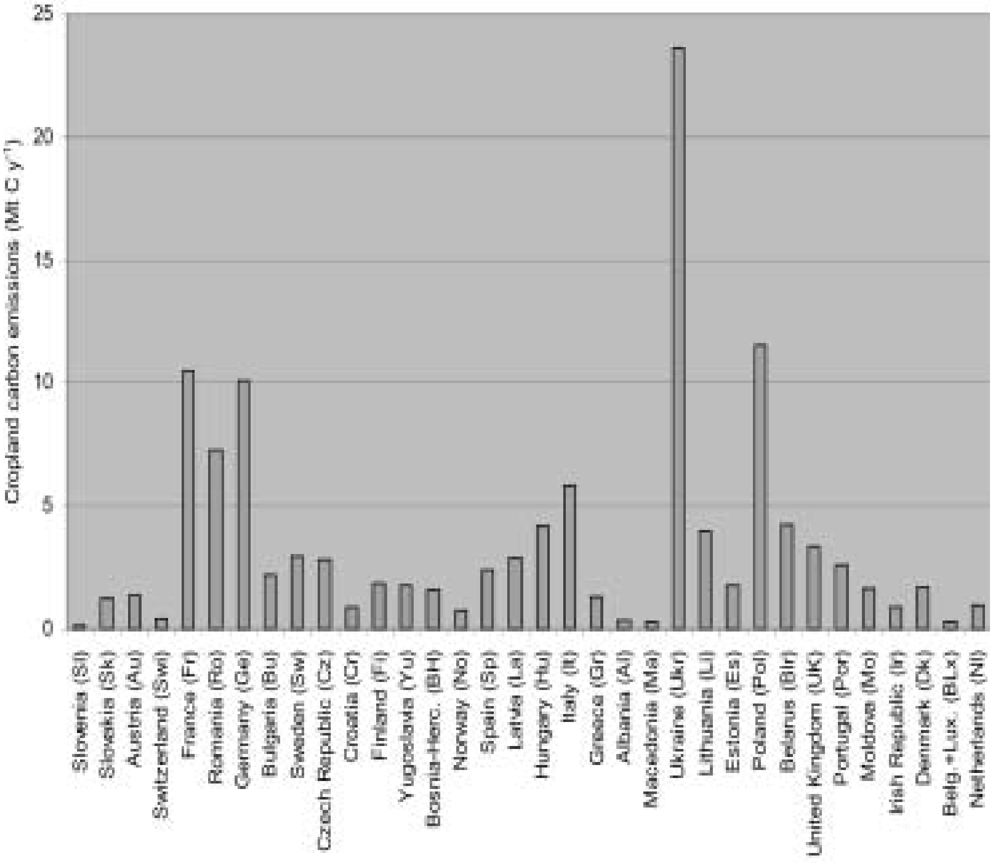
Figure 4.3 Total emissions of methane and nitrous oxide from agriculture in Million kg CO_2 equivalents



4.4 Carbon dioxide emissions (1990 to 2000)

CO_2 carbon emissions from European cropland were estimated to be 78 (SD: 37) Mt C y^{-1} for the EU-15 (Vleeshouwers & Verhagen, 2002), 300 Mt C y^{-1} for geographical Europe as far east as the Urals (Janssens *et al*., 2003) and 120 Mt C y^{-1} for the same area by Janssens *et al.* (2004). Countries with a larger cropland area tend to have larger fluxes of cropland CO_2. Figure 4.4 shows the cropland CO_2 carbon emissions from European countries (plotted from values in Janssens *et al*., 2004). Separate estimates for 1990 and 2000 are not available.

Figure 4.4 Cropland carbon emissions (Mt C y^{-1}) from European countries (plotted from values in Janssens et al., 2004).



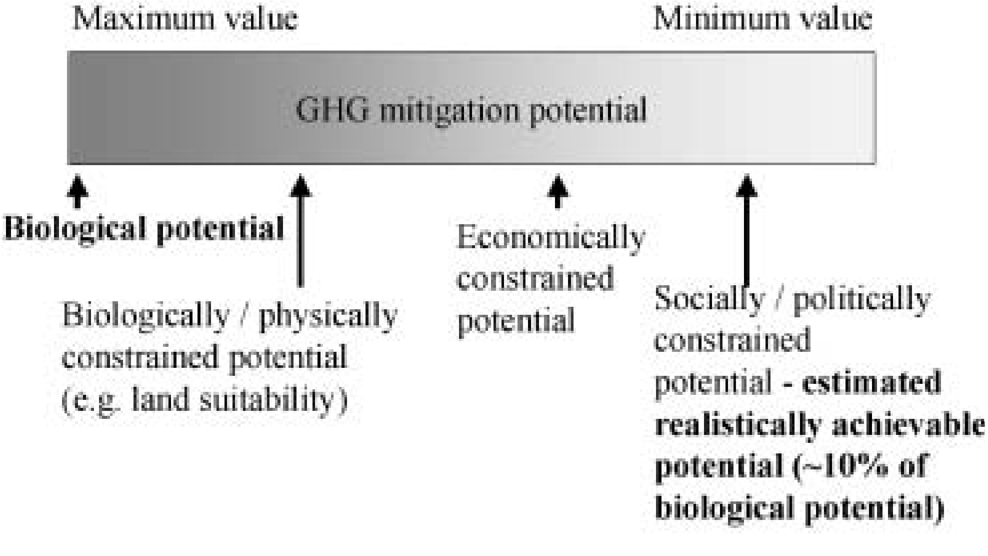
5. Mitigation options in agriculture

The political context for agricultural GHG mitigation arises from the Kyoto Protocol to the 1992 United Nations Framework Convention on Climate Change (UNFCCC) and its subsequent elaboration at the 7th Conference of Parties (COP7) leading to the Marrakech Accords. This allows biospheric carbon sinks (and sources) to be included in attempts to meet Quantified Emission Limitation or Reduction Commitments (QELRCs) for the first commitment period (2008-2012), as outlined in the Kyoto Protocol (available at: www.unfccc.de). Under article 3.4 of the Kyoto Protocol, the activities forest management, cropland management, grazing land management and re-vegetation are included. Soil carbon sinks (and sources) can therefore be included under these activities. Further, direct emission reductions of the greenhouse gases nitrous oxide (N_2O) and methane (CH_4) will help parties to meet QELRCs. Agricultural GHG mitigation can therefore directly contribute to political GHG reduction targets.

For CO_2 emissions, in terms of the mechanism by which these mitigation options are assessed, parties electing to include cropland management, grazing land management and re-vegetation need to account for changes in these soil carbon sinks and sources on a net-net basis. This means that they must compare the net flux of carbon from a given activity during the commitment period with the equivalent net flux of carbon in the baseline year (usually 1990). Carbon sequestration in cropland soils, or even a reduction in a flux to the atmosphere compared to the baseline year, can therefore be used by a party to the UNFCCC in helping to meet emission reduction targets. Methane and nitrous oxide are already accounted for on a net-net basis within the national GHG inventory and reduction of emissions of these gases are also accounted for as a direct emission reduction.

Estimation of mitigation potential is often confounded by the choice of constraints. Some authors quote biological potentials (Metting *et al*., 1999), others quote potentials as limited by available land or resources (Smith *et al*., 2000a), and others also consider economic and social constraints (Cannell, 2003; Freibauer *et al*., 2004). Smith (2003a) provided a figure showing how these mitigation potential estimates differ and how the potential is reduced by a number of constraints (Figure 5.1).

Figure 5.1 How different constraints reduce the GHG mitigation potential from its theoretical biological maximum to realistically achievable potentials that are much lower (adapted from Smith, 2003a)



An analysis of the estimates presented in Freibauer *et al*. (2004) and the assumptions used by Cannell (2003) suggest that the realistic sustainable (or conservative) achievable potential of GHG mitigation (taking into account limitations in land use, resources, economics, and social and political factors) may be about 10-20 percent of the biological potential. Although this value is derived predominantly from expert judgment, it may be useful in assessing how different estimates of GHG mitigation potential can be compared and how they might realistically contribute to GHG stabilization.

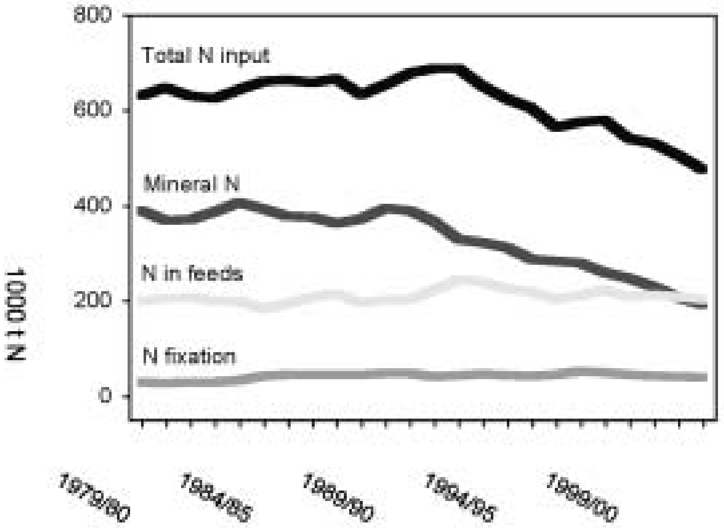
Given the recognised biological, economic, social, political and institutional constraints on the implementation of GHG mitigation measures, the scale of GHG mitigation in agriculture will rely more upon overcoming these constraints than upon filling in gaps in our scientific and technical knowledge. Further consideration needs to be given to the scale of implementation of the mitigation options. GHG mitigation needs to be encouraged by policy measures. Action is required at the governmental (national and EU) level, but ultimately, management is implemented at the farm-scale by farmers and land managers (see below). Managing the diverse interests of the range of interested parties (policy makers, farmers, land managers, environmental groups and the wider public) will not be easy. It is likely that a combination of measures will be required to overcome the many constraints to GHG mitigation in agriculture and may include incentives, regulations and education.

For successful implementation, mitigation options need to have direct relevance to the farmers / land-managers. Mitigation options for a single gas (e.g. N_2O in Scotland by Ball & Scott, 1997) tend to be ignored as there is no incentive for the farmer/land manager to use them and they exclude consideration of other pollutants. Whether or not a particular management option is possible or desirable will depend upon the style and type of farm for which it is being considered. For example, reduced tillage is unlikely to be an option on an organic farm where herbicides cannot be used, and mechanical weeding is the only possible method of weed control. In practice, mitigation measures may be more acceptable and recognizable if they are specified at the farm level, where issues such as relocation or replacing certain activities are at stake upon adoption of given measures. A “farm gate” approach (i.e. a whole-farm input / output balance) may be valuable in assessing the acceptability of suggested GHG mitigation options, especially in the definition, execution and communication of GHG mitigation options.

GHG mitigation measures could be grouped into best management packages, appropriate for each farm type / style, and farmers could then be allowed to select the package or options that best fit their farm style and conditions. Mitigation can often be achieved simply be improving agronomy and fertiliser management e.g. by increasing fertiliser use efficiency. This enables increases in both productivity and environmental benefits at the same time – the ‘win-win’ situation. Other possibilities to improve GHG mitigation measure uptake include, improving the skill of farmers through education and communication and getting climate change and mitigation understood by the farmer both as concept and perception. Simple knowledge transfer such as improved fertiliser recommendations taking into account fertiliser type and the need for mitigation would bring substantial benefits relatively cheaply. Involving farmers at an early stage, by encouraging active participation of farmers will help farmers to recognize how management affects emissions and C stock changes, and that credits and accounting are possible. There needs to be a close dialogue between farmers, policy makers, scientists and the public to consider the image of farming as a sound basis for good farmers. More broadly, the horizontal and vertical organisation of farms needs to be optimised. To be accepted by farmers, GHG mitigation measures need to represent socio-economically attractive investment.

As well as on-farm management, general regulations may reduce GHG emissions. Reducing the total input of fertiliser N has a major impact on N_2O emission levels. Hence, regulation to restrict and optimise the use of fertilisers may also be an effective means to mitigate N_2O emissions (and in compliance with other goals like the nitrate directive). Figure 5.2 shows the N inputs to Danish agriculture since the early eighties. It shows that a more effective use of N inputs can be achieved and lead to a significant reduction in the use of mineral N and N_2O emission (Table 4.1.2f). The regulation of N application rates and timing is also an N_2O mitigation option.

Figure 5.2 N inputs to Danish agriculture since the early eighties.



However, because of the complexities of the soil processes involved, there is no linear correlation between N input and N_2O emission, and thus no correlation between reduced N input and reduced N_2O emission at the field scale. So whilst a reduction in N inputs may reduce N_2O emissions in total, seasonal variations in weather, and therefore soil conditions, determine when the N_2O fluxes occur (Dobbie & Smith, 2003; Kaiser & Ruser, 2000). Further systematic studies in different climatic regions on how emissions vary with management practices such as fertilizer type, rate, timing and application method, crop type and cropping history as well as soil type and weather conditions are needed to provide a better understanding of the determinants and underlying processes of N_2O emission.

At the farm scale, the following elements, issues and decisions are important, and need to be considered when assessing the applicability of GHG measures to individual farms:

1) farm management skills,
2) livestock / manure management
    a. livestock density / production intensity,
    b. land use change (e.g. conversion to forests, permanent wetland, permanent set-aside),
    c. import of organic matter in composts, manures and sewage sludge (organic amendments),
    d. feed and fertiliser import,
    e. export of manure (e.g. fermentation plant), residues e.g. straw
3) crop rotation
    a. Grassland (permanent or rotational), arable crops, bioenergy crops, permanent crops (fruits)

  - b. legume crops (N-fixation)
  - c. cover crops
  - d. soil management (tillage, crop residues)
  - e. nutrient management (manure, mineral fertiliser, amount, timing, application method)
  - f. crop management (sowing (e.g. reseeding of grass), crop protection, harvesting, grazing)

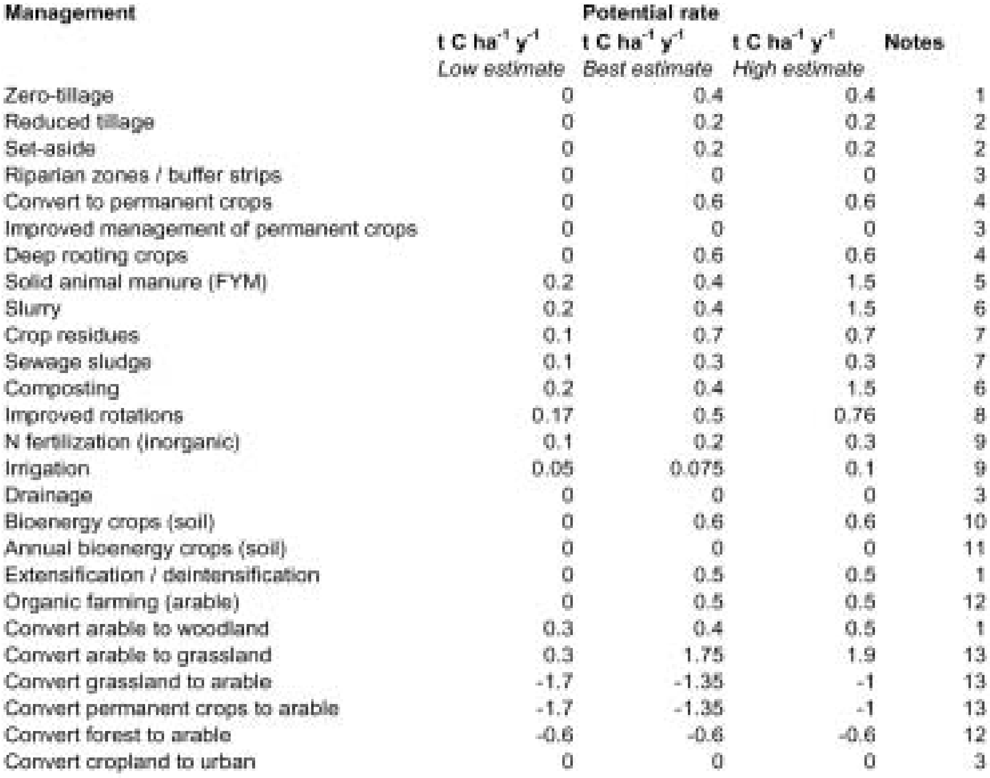
4) animals
   - a. feeding practice
   - b. manipulation of rumen microflora
   - c. breed
   - d. age of animals (e.g. age before slaughtering, number of lactations in cows)
5) feed stores
   - a. Storage conditions (no emissions for good silage)
6) housing
   - a. manure handling system (time and type of storage in house)
   - b. mechanical/natural ventilation
7) manure store
   - a. manure type
   - b. storage conditions (e.g. cover on slurry tanks)
   - c. processing (e.g. anaerobic digestion, turning for composting)
8) other sources/sinks
   - a. animal walkways and collection yards
   - b. ditches
   - c. hedges
   - d. buffer strips (e.g. for erosion control)
   - e. set-aside (marginal, degraded or highly erodible), and similarly another
9) indirect sources of GHG
   - a. ammonia volatilisation
   - b. nitrate leaching
   - c. dissolved N_2O and CH_4 in drainage waters
10) fossil fuel usage
11) irrigation

At the policy level, mitigation measures are perhaps best encouraged as part of a broader environmental agenda. Smith & Powlson (2003) and Smith (2003a, 2004a) argue that GHG mitigation needs to be tackled hand in hand with other related problems. For example, the IPCC (2001a) have noted that global, regional and local environmental issues such as climate change, loss of biodiversity, desertification, stratospheric ozone depletion, regional acid deposition and local air quality are inextricably linked. GHG mitigation clearly belongs on this list. The IPCC (2001a) further noted that recognising the linkages among environmental issues, and their relationship to meeting human needs, provides an opportunity to address global environmental issues at the local, national and regional level in an integrated manner that is cost-effective and meets sustainable development objectives. The importance of integrated approaches to sustainable environmental management is becoming ever clearer (Smith, 2003b).

Though there are often co-benefits of GHG mitigation measures (e.g. positive effects on biodiversity, erosion control, fertility, soil moisture), there may also be conflicts. For example, extensive areas that are managed for biodiversity may have low soil carbon values (but see Falloon *et al.*, 2004 where the opposite is the case), and agricultural areas placed under long-term GHG mitigation management may reduce the adaptive capacity of the agricultural sector. As discussed earlier, one must also consider the trade off between GHGs and other implications for fossil fuel use (e.g. pre-chain fossil fuel use in fertiliser and herbicide production [see Frye 1984, Lal, 2004], and fuel carbon costs for transport, crop drying and processing and field management practices [e.g. Smith & Smith, 2000; Lal, 2004]). Wherever possible "win-win" options (whereby benefits accrue through other means, e.g. increased fertility or production) should be targeted (Lal *et al.*, 1998; Smith, 2003a) as should "no regrets" options (whereby the management practice yields immediate benefits as well as potentially in the future; Smith & Powlson, 2003; Smith 2004a). In addition to attempting to solve several environmental problems together, social and economic problems also need to be addressed in the same package. All of the scientific and technical measures outlined in this paper have the potential to enhance C sinks, but the extent to which these are sustainable also needs to be considered (Smith 2003b).

Mitigation options in croplands are listed in table 5.1 below along with low, mean/best and high estimates of the mitigation potential of each practice. The values shown in Table 5.1 were combined with estimated areas under each practice in four European countries and for EU-15 in 1990, 2000 and estimates for 2010 (see appendix 2) to calculate the yearly cropland soil carbon sequestration potentials for 2000 and 2010 relative to 1990 cropland management shown below in figures 5.3 and 5.4.

Table 5.1 GHG mitigation options for croplands. Low, best and high estimates (see notes)



Management	**Potential rate**			
	t C ha^{-1} y^{-1} *Low estimate*	**t C ha^{-1} y^{-1}** *Best estimate*	**t C ha^{-1} y^{-1}** *High estimate*	**Notes**
Zero-tillage	0	0.4	0.4	1
Reduced tillage	0	0.2	0.2	2
Set-aside	0	0.2	0.2	2
Riparian zones / buffer strips	0	0	0	3
Convert to permanent crops	0	0.6	0.6	4
Improved management of permanent crops	0	0	0	3
Deep rooting crops	0	0.6	0.6	4
Solid animal manure (FYM)	0.2	0.4	1.5	5
Slurry	0.2	0.4	1.5	6
Crop residues	0.1	0.7	0.7	7
Sewage sludge	0.1	0.3	0.3	7
Composting	0.2	0.4	1.5	6
Improved rotations	0.17	0.5	0.76	8
N fertilization (inorganic)	0.1	0.2	0.3	9
Irrigation	0.05	0.075	0.1	9
Drainage	0	0	0	3
Bioenergy crops (soil)	0	0.6	0.6	10
Annual bioenergy crops (soil)	0	0	0	11
Extensification / deintensification	0	0.5	0.5	1
Organic farming (arable)	0	0.5	0.5	12
Convert arable to woodland	0.3	0.4	0.5	1
Convert arable to grassland	0.3	1.75	1.9	13
Convert grassland to arable	-1.7	-1.35	-1	13
Convert permanent crops to arable	-1.7	-1.35	-1	13
Convert forest to arable	-0.6	-0.6	-0.6	12
Convert cropland to urban	0	0	0	3

Notes: 1 = From Smith *et al*. (2000a); Freibauer *et al*. (2004), 2 = Assumed to be half of the no-till potential of Smith *et al*. (2000a); Freibauer *et al*. (2004), 3 = No data on which to base an estimate, 4 = As in Freibauer *et al*. (2004), assumed to be the same as bioenergy crops, 5 = Low and best estimates from Smith *et al*. (2000a) of dm basis; high estimate from Vleeshouwers & Verhagen (2002), 6 = Assumed to be as for FYM on a dm basis - low and best estimates from Smith *et al*. (2000a) on dm basis; high estimate from Vleeshouwers & Verhagen (2002), 7 = Low estimate from IPCC (2000), best and high estimates from Smith *et al*. (2000a); Freibauer *et al*. (2004), 8 = Range from IPCC (2000) - best estimate is rough mean from this range, 9 = Range from Lal *et al*. (1998), 10 = From Smith *et al*. (2000a), 11 = No evidence that these are different from any different from other crops, 12 = From Freibauer *et al*. (2004), 13 = Range from Vleeshouwers & Verhagen (2002); Freibauer *et al*. (2004).

Figure 5.3 Yearly cropland soil carbon sequestration potential by 2000 compared to 1990 for EU-15, UK, Sweden, Belgium and Finland

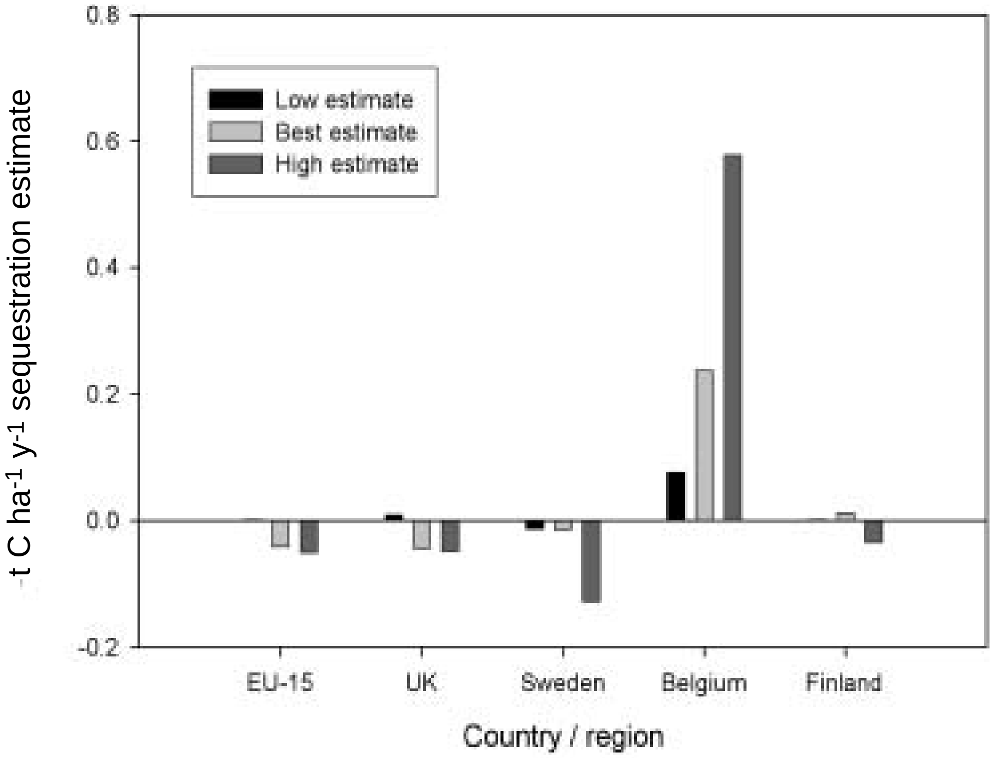
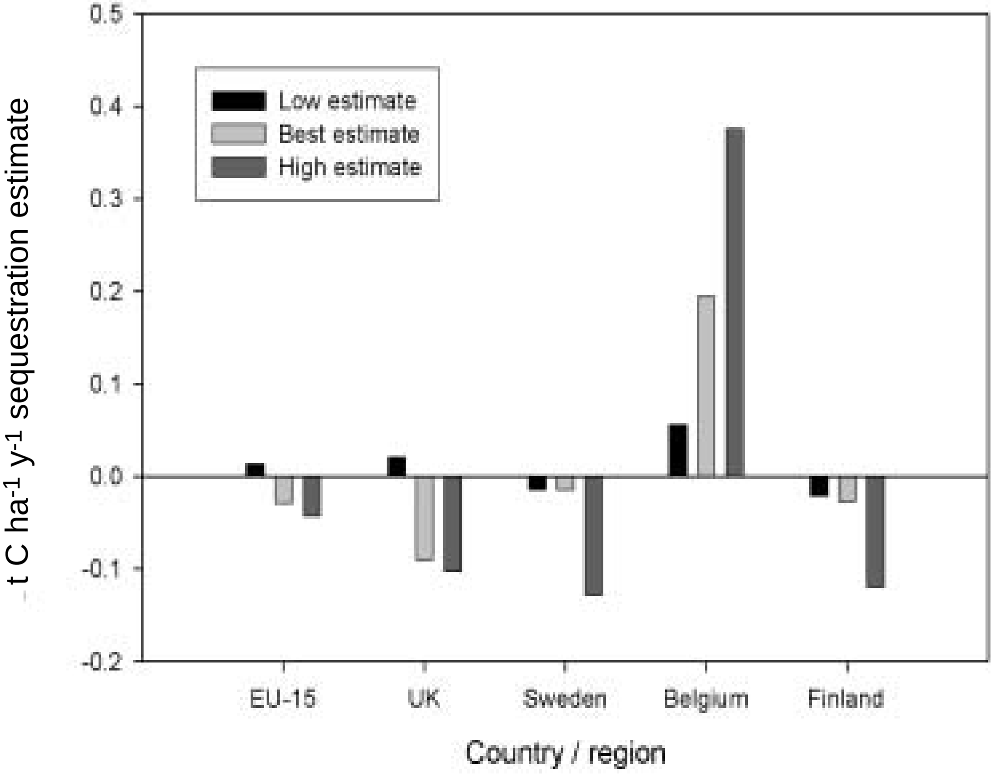


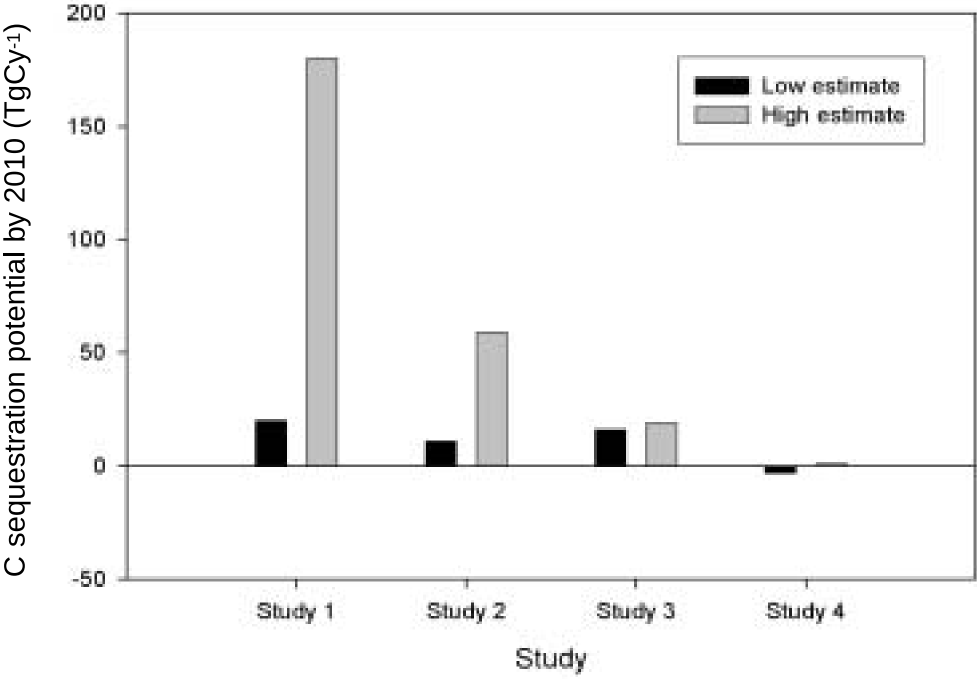
Figure 5.4 Yearly cropland soil carbon sequestration potential by 2010 compared to 1990 for EU-15, UK, Sweden, Belgium and Finland



The low (and also negative) carbon sequestration potentials for the EU-15 and all countries except Belgium reflect that in many countries total cropland area and/or areas under carbon enhancing management have decreased from 1990 to 2000. Based on current trends and expert judgement, extrapolation to 2010 suggests that this trend will not be reversed by 2010 (see appendix 2 for further details). The only C enhancing practice that has increased from 1990 to 2000 is organic farming (see appendix 2), and this practice is set to increase further between 2000 and 2010. Belgium is the only country examined in which cropland management appears to have increased cropland soil carbon sequestration from 1990 to 2000 and where it is projected to increase further to 2010 (Dendoncker *et al.*, 2003) The results also show the importance of assessing GHG mitigation potential at national / regional level as well as at larger (EU-15 wide) scales since the local management and estimates of the mitigation potential can be very different.

These estimates, based on measured trends in areas under each management practice in Table 5.1 from 1990 to 2000, and on projections of current trends to 2010 are in sharp contrast with biological mitigation potentials from previous studies. Figure 5.5 shows the estimates of previous studies of C mitigation potential in Europe under various assumptions. The difference between the estimates presented here and those in previous studies is that they aimed to show what could be achieved. As pointed out in many of these studies, without active encouragement, changes in cropland management practice will not occur. This study suggests that in most countries, and in the EU-15 as a whole, cropland management has not increased soil C sequestration since 1990 and is not predicted to increase it significantly by 2010, except in Belgium.

Figure 5.5 Estimates of cropland soil carbon sequestration potential in EU-15 from previous studies and from this study. See notes for details.



Notes: Study 1 is from Vleeshouwers & Verhagen (2002) with the low estimate for straw incorporation and the high figure for conversion of all cropland to grassland. Study 2 is from Smith *et al*. (2000a) with figures scaled from geographical Europe (including Baltic States but excluding Russia) to EU-15 as per Smith *et al*. (1997). The low estimate is from the combined land management scenario with extensification of surplus arable land and straw incorporation; the high estimate is for the combined "optimal" scenario (see Smith *et al*., 2000a for further details). Study 3 is from Freibauer *et al*. (2004) with values assessed for realistically achievable potential by 2010 (about 1/5 of the estimated biological potential). Study 4 is this study with figures based on measured trends 1990 to 2000 and extrapolations to 2010 (see appendix 2 for further details).

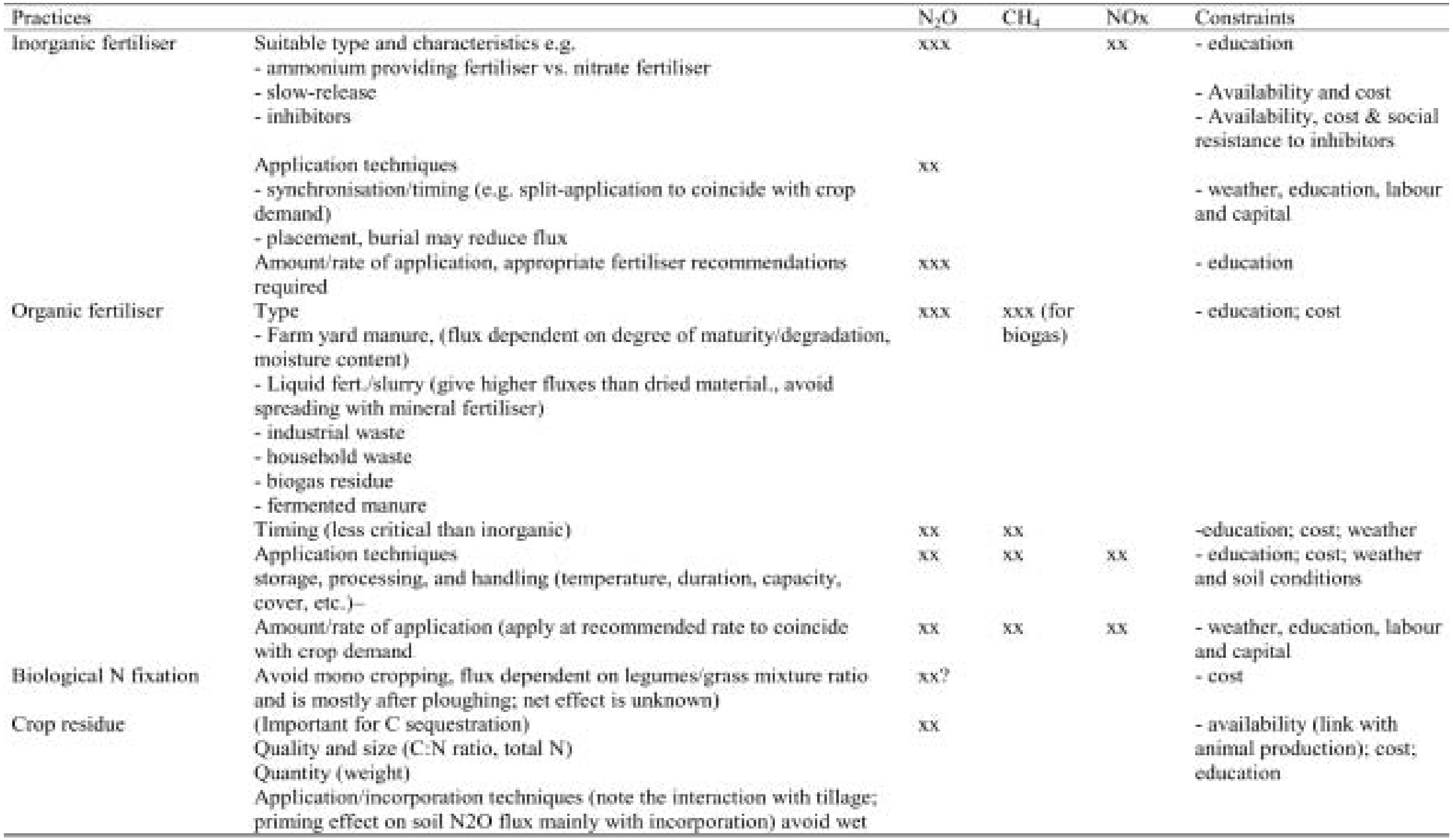
Farming of organic soils can also cause C loss so restoration of peatlands could reduce GHG fluxes. Virgin peatlands take up carbon at rates between 0.1 and 0.3 t C ha^{-1} y^{-1}, but emit CH_4 at significant rates, turning them into a source of 0.16 (range: 0.14 to 1.5) t ha^{-1} y^{-1} C-equivalents (Cannell & Milne, 1995). The cultivation of peatlands releases carbon by rapid peat oxidation, at a rate of 2.2 to 5.4 t C ha^{-1} y^{-1} (min: 2.2, max: 31 t C ha^{-1} y^{-1}; Kasimir Klemedtsson *et al*., 1997, Freibauer, in press). Carbon losses increase with deep drainage and intensive mechanical soil disturbance, especially after deep ploughing (Kasimir Klemedtsson *et al*., 1997). Whilst CH_4 emissions more or less cease completely after drainage, N_2O emerges at rates that exceed those from mineral agricultural soils by a factor of 2 to 10. In total, average greenhouse gas emissions from agricultural peat soils are estimated to range between 3.5 (2.2 to 5.2) t ha^{-1} y^{-1} C-equivalents in grasslands, 4.9 (3.3 to 6.5) in croplands, and 6.5 (3.8 to 9.5) under potato or sugar beet (Freibauer, in press). Large variability in C losses is mainly caused by differences in drainage, climate, fertility and peat type (Aerts & Toet, 1997, Chapman & Thurlow, 1996, Kasimir Klemedtsson *et al*., 1997). Decomposition rates after drainage in eutrophic peats are higher than in oligotrophic peats (Minkkinen *et al*., 1998). In the context of carbon sequestration, the rationale for alternative use of peatlands is the preservation of the existing large carbon stocks in peat soils and the reduction of anthropogenic greenhouse gas emissions rather than an increase of soil carbon stocks in the short term (Komulainen *et al*., 1999). On the other hand, peat carbon losses may be compensated by enhanced vegetation growth (Cannell *et al*., 1993, Minkkinen *et al*., 1998), so only a full greenhouse gas budget reveals the climatic benefit of rewetting drained peatlands.

Potential alternative uses of agricultural peat soils include the avoidance of potatoes and sugar beet, avoidance of deep ploughing, maintenance of a more shallow water table and the conversion of arable cropping to permanent cultures as well as new crops on restored wetlands. Restoration and conservation of peatlands can play a significant role in agricultural GHG mitigation, as can raising the water table of farmed peatlands (Friebauer *et al*., 2004)

Non-CO_2 greenhouse gas mitigation possibilities are outlined in Table 5.2. As for Table 2.1, a ranking of the likelihood of the reduction in emission is given for N_2O, CH_4 and NO_x.

xxx, xx and x refer to a high, moderate and low likelihood of significant mitigation.

Table 5.2. Mitigation of non-CO_2 greenhouse gases. (Note: ranking is applied in rows only)

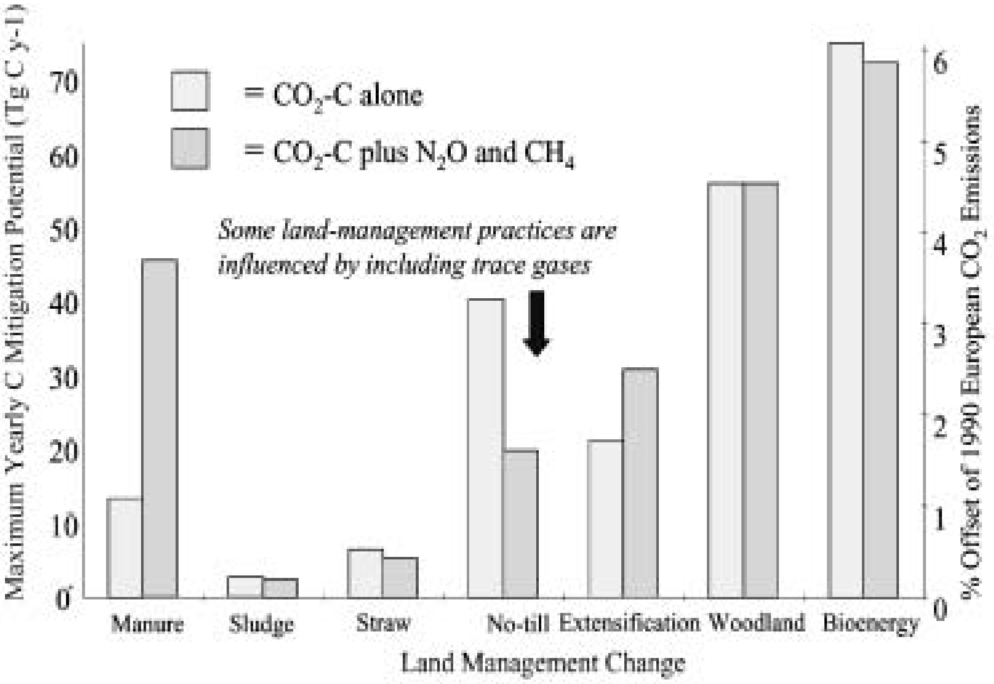


Practices		N_2O	CH_4	NOx	Constraints
Inorganic fertiliser	Suitable type and characteristics e.g. - ammonium providing fertiliser vs. nitrate fertiliser	xxx		xx	- education
	- slow-release				- Availability and cost
	- inhibitors				- Availability, cost & social resistance to inhibitors
	Application techniques	xx			
	- synchronisation/timing (e.g. split-application to coincide with crop demand)				- weather, education, labour and capital
	- placement, burial may reduce flux				
	Amount/rate of application, appropriate fertiliser recommendations required	xxx			- education
Organic fertiliser	Type - Farm yard manure, (flux dependent on degree of maturity/degradation, moisture content) - Liquid fert./slurry (give higher fluxes than dried material., avoid spreading with mineral fertiliser) - industrial waste - household waste - biogas residue - fermented manure	xxx	xxx (for biogas)		- education; cost
	Timing (less critical than inorganic)	xx	xx		-education; cost; weather
	Application techniques storage, processing, and handling (temperature, duration, capacity, cover, etc.)–	xx	xx	xx	- education; cost; weather and soil conditions
	Amount/rate of application (apply at recommended rate to coincide with crop demand	xx	xx	xx	- weather, education, labour and capital
Biological N fixation	Avoid mono cropping, flux dependent on legumes/grass mixture ratio and is mostly after ploughing; net effect is unknown)	xx?			- cost
Crop residue	(Important for C sequestration) Quality and size (C:N ratio, total N) Quantity (weight) Application/incorporation techniques (note the interaction with tillage; priming effect on soil N2O flux mainly with incorporation) avoid wet	xx			- availability (link with animal production); cost; education

Practices		N_2O	CH_4	NOx	Constraints
	conditions				
Farming system & mgt.	Extensive cropping may be better than intensive - further research needed for to assess this difference and the effect of the arable/livestock ratio. Also compare to intensive areas with other land use on spare land	-	-	-	Need further research
Tillage	Important for C sequestration but interacts with soil physical conditions Ploughing or deep ploughing may reduce trace gas emissions but decrease carbon sequestration Conservation (reduced) tillage may be intermediate but more information required	-	-	-	Need further research; education
Crop rotation	Catch crops reduce bare soils (possible link to BNF) amelioration crops (crop type i.e. deep rooting or shallow rooting)	xx		x	- cost
Water management	Drainage useful but irrigation should be avoided, flooding water buffers may have an effect	xxx	xxx		- cost; further research
Compaction status	Appropriate timing and size of machinery required Manage grazing to avoid poaching	x		x	- education; cost
Animal management	Manipulate Diet composition, feed additives, and technological Treatment of feed Level of intake Animal productivity/genetics Intensity of system of animal production Ratio of meat/milk production Housing system Storage capacity for manure Age of slaughtering Manure management	x	xxx		- animal welfare; cost; education; social demand
Grazing intensity	Stock numbers and type of grass conservation	x	xxx		- policies
Biomass burning and biomass production.	Avoid burning and use good practices in biomass production	xx	x	xx	- needs further research

Previous studies for Europe have shown that including non-CO_2 GHG fluxes in calculations of GHG mitigation potential can significantly alter estimates based on carbon dioxide mitigation alone. Figure 5.6 (from Smith *et al.*, 2001) shows that for some management practices (e.g. no till agriculture), up to 50% of the CO_2-only mitigation potential can be lost when non-CO_2 GHGs are included. Given that CH_4 and N_2O emissions are of a similar order to CO_2 emissions when all fluxes are expressed as CO_2-carbon equivalents (see section 2), non-CO_2 GHGs must be considered alongside CO_2 emissions.

Figure 5.6 GHG mitigation potential of various cropland management options (expressed as CO_2-C equivalents) when considering CO_2-C alone or when including the non-CO_2 GHGs nitrous oxide and methane. Adapted from Smith et al. (2001).



• 6. Verification

Verification for national greenhouse gas inventories (from the IPCC, 2001b; Good Practice Guidelines) refers to 'the activities and procedures that can be followed to establish the reliability of the data. This usually means checking the data against empirical data or independently compiled estimates.' This differs from validation, which is defined as 'checking that the emissions and removals data has been compiled correctly in line with reporting instructions and guidelines'. If verification is interpreted strictly, estimates would be required for GHG fluxes that are independent of those used in the national report of the party to the UNFCCC. This means that for a given activity, there must be at least two independent methods for assessing the size of a GHG emission.

For cropland GHG fluxes, Smith (2004b) suggests that, if a stringent definition were used, no party would be able to meet the criteria. However, most countries would be able to meet the verification criteria by 2010 if the least stringent definition of verification were adopted (i.e. reporting of areas under a given practice [without geo-referencing] and the use of default methods and emission factors to infer a change in emissions). This approach is consistent with the Tier 1 approach of the new IPCC Good Practice Guidance on Land Use Change and Forestry (IPCC, 2004) though the Good Practice Guidance suggests that national / regional values should be used to replace defaults where they are shown to be more accurate than default values (Tier 2) or that more complex methods should be used where available (Tier 3).

For an intermediate stringency of definition (i.e. where areas under a given practice are geo-referenced [from remote sensing or ground survey], changes in carbon are derived from controlled experiments on representative climatic regions and on representative soils [or modelled using a well-evaluated, well-documented, archived model] and intensively studied benchmark sites are available for verification), only countries with the best developed inventory systems will be able to meet the requirements. Since most countries could meet verification targets if the least stringent definition of verification is used, this is the most likely to be adopted.

As in the compilation of the greenhouse gas inventory, the availability and quality of data are limiting factors for adequate verification. It is difficult in some countries even to collect reliable activity data (e.g. areas under cropland management), and much more difficult still for countries to provide data on areas under a given management practice (such as straw incorporation or zero tillage). Farm level accounting would help but would be prohibitively expensive unless collected in combination with other census data. Even if it were possible to collect data on the practices declared by a farmer / land manager, it will remain extremely difficult to verify how reliably the farmer / land-manager is implementing this practice.

Verification of mitigation measures targeting methane and nitrous oxide may be more straightforward to the extent that these involve reductions in activities, i.e., number of animals in a given category or amounts of N applied.

From the scientific perspective, the EU wishes (through projects such as CarboEurope) to obtain independent estimates of national and EU-wide GHG fluxes to verify the figures provided in national GHG inventories. At the broad level, this is possible, for example by assessing the overall C balance for Europe, but at the level of individual country inventories this may prove very difficult due to a) the limited ability to spatially allocate emissions (and sinks) and b) the very different aim of a research project such as CarboEurope and the aims of a targeted multi-source, multi-sector verification programme. The dual constraint approach of CarboEurope (i.e. using top-down and bottom-up approaches to verify national inventories) works best with CO_2. For N_2O and for CH_4 it is possible to measure fluxes by micrometeorological methods with a network of high towers, but this measures all sources together and it is not possible to allocate measured sources to agriculture or land use. At the plot level, many of the measurements being undertaken within CarboEurope (e.g. flask measurements, eddy covariance, chamber measurements, SOC stock changes), will be very useful for verification purposes.

At the plot scale, there are two complementary methods of estimating a carbon flux, either by measurement of the CO_2 flux itself, or via measuring a change in the SOC stock (see IPCC method; section 3.3). For N_2O and CH_4, this is not possible and direct flux measurements are required. Well-documented, validated and archived dynamic simulation models may have a role to play in verification, but this raises other issues of verifiability. Other considerations include accuracy, cost and spatial variability. Smith (2004b) discusses the issue of verification (for SOC stock changes) in detail.

• 7. Conclusions: significant research needs

In this report we have summarised our current knowledge on GHG emissions from European croplands, the methods to account for GHG emissions, possible GHG mitigation options in European croplands and the constraints upon implementation of these measures. We have also provided estimates of *a)* the GHG fluxes from croplands in 1990, 2000 and likely fluxes by 2010 and of *b)* the extent to which cropland management options can mitigate GHG emissions for 1990, 2000 and 2010. We also note that the cropland CO_2 flux in Europe is the largest and most uncertain of all terrestrial C fluxes (Janssens *et al.*, 2003). We also acknowledge that the fluxes of GHGs from croplands (especially from soils) are the least well understood of any of the European fluxes and that there is an urgent need for further research in this area. Research priorities lie in a number of areas as detailed below.

Soil process studies in agriculture: Carbon dioxide and other greenhouse gas fluxes are dominated by soil fluxes. More research is required on how agricultural management affects GHG fluxes and soil processes involved in GHG emissions and C sequestration. Specifically, research is required on conservation tillage, biological nitrogen fixation (organic systems), extensive farming and biomass production systems. Studies might involve a combination of GHG flux measurements, detailed soil analysis, spatial variability of soil type and wetness, isotope labelling, process-modelling and meta-analysis of existing data sets from European experiments. ‘Pollutant-swapping’ aspects should also be integrated within these studies.

Data / inventory collation and meta-analysis: Some data exist on agricultural management (and soil characteristics) at the European, national, sub-national and farm scales, but is not readily available for modelling and up-scaling. Since agricultural management is a key driver of GHG emissions, a work-programme to collect, collate and make available this data is urgently required. A meta-analysis using this data to calculate response factors for N_2O and CH_4 oxidation with respect to driving variables, e.g. climate, soil type, fertiliser type, soil organic C content, etc. is also required. Statistical approaches should be developed / improved to optimise data collection (where, when and what to measure).

Development of future land-use and land management scenarios: For extrapolating in to the future, new agricultural management and land-use scenarios need to be developed for the 21st Century.

Development of new technologies: Some experimental techniques to non-invasively measure soil C levels (tritium probe, multi-spectral RS, infra-red analysis) show some promise and should be developed to make the technologies usable to improve monitoring and verification networks.

Coupling of the C & N cycles: Since agriculture is driven by N fertiliser additions, and a significant GHG flux from agriculture can be from nitrogenous compounds (such as nitrous oxide), a closer link between carbon and nitrogen cycling in research, and the understanding of these processes (through process studies and modelling) is urgently required.

Assessment of total GHG budget: All studies on agriculture should attempt to assess the combined impact of agricultural management, climate, and indirect effects (such as increasing atmospheric CO_2 concentrations and N deposition) on all biospheric GHGs (CO_2, N_2O and CH_2), not just CO_2 which has dominated previous studies.

Mitigation options: Assessment of realistic mitigation and adaptation options in agriculture is needed at various scales, including the farm scale at which the management is practiced. These need to be assessed not only for biological potential but also for economic viability, and for social, institutional and policy constraints and for potential side effects. Some R&D on knowledge transfer may also be merited as successful mitigation depends heavily on this.

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• Appendix 1. Summary of IPCC default methods to estimate GHG emissions

The IPCC suggests default methods for estimating emissions of GHGs from agriculture and land-use change. Nitrous oxide and methane emissions are accounted for under the agricultural sector (Chapter 4 of the Revised 1996 IPCC guidelines for National Greenhouse Gas Inventories; IPCC, 1997) whereas carbon dioxide emissions are estimated in the land-use change sector (Chapter 5 of the Revised 1996 IPCC guidelines for National Greenhouse Gas Inventories; IPCC, 1997). Since field burning of agricultural residues is no longer permitted within the EU, these are not discussed here.

A1.1 Nitrous oxide

The information in this section is taken directly from Chapter 4 of the Revised 1996 IPCC guidelines for National Greenhouse Gas Inventories (IPCC, 1997). Three sources of N_2O are distinguished in the IPCC methodology (IPCC, 1997): (*i*) direct emissions from agricultural soils, (*ii*) direct soil emissions from animal production (including emissions from housing to be reported under Manure Management (Section 4.2) – not discussed further in this cropland report), and (*iii*) N_2O emissions indirectly induced by agricultural activities.

Anthropogenic input into agricultural systems includes synthetic fertiliser, nitrogen from animal wastes, nitrogen from increased biological N-fixation, and nitrogen derived from cultivation of mineral and organic soils through enhanced organic matter mineralisation. Nitrous oxide may be produced and emitted directly in agricultural fields, animal confinements or pastoral systems or be transported from agricultural systems into ground and surface waters through surface runoff, nitrogen leaching, consumption by humans and introduction into sewage systems which transport the nitrogen ultimately into surface water. Ammonia and oxides of N (NO_X) are also emitted from agricultural systems and may be transported off-site and serve to fertilise other systems which leads to enhanced production of N_2O.

Under the IPCC methodology, agricultural systems are considered as being the same throughout the world and this methodology does not take into account different crops, soils and climates, which are known to regulate N_2O production. These factors are not considered because limited data are available to provide appropriate emission factors. The method also uses a linear extrapolation between N_2O emissions and fertiliser nitrogen application and in the indirect emissions section does not account for the probable lag time between nitrogen input and ultimate production of N_2O as a result of this nitrogen input into agricultural soils.

A1.1.1 Direct nitrous oxide emissions from soils

Most studies on N_2O emissions from agricultural soils investigate the difference in N_2O production between fertilised and unfertilised fields. Emissions from unfertilised fields are considered background emissions. However, actual background emissions from agricultural soils may be higher than historic natural emissions as a result of enhanced mineralisation of soil organic matter. This is particularly observed in organic soils in both cold and warm climates over the globe. Background emissions may also be lower than historic emissions due to depletion of soil organic matter (IPCC, 1997).

According to IPCC (1997), the following sources and sinks of N_2O can be distinguished.

- Synthetic fertilisers;
- Animal excreta nitrogen used as fertiliser;
- Biological nitrogen fixation;

- Crop residue and sewage sludge application;
- Glasshouse farming (not dealt with in this report);
- Cultivation of soils with a high organic content;
- Soil sink for N_2O.

Within the IPCC methodology, all of these N_2O sources are included in the methodology, except for sewage sludge application and the soil sink for N_2O. These sources and sinks are not estimated because emissions are negligible or data are insufficient.

A1.1.1.1 Synthetic fertilisers

Synthetic fertilisers are an important source of N_2O. Reviews of N_2O emissions after fertiliser addition led to an IPCC estimate of 0.0125 ± 0.01 of the applied nitrogen being directly emitted as N_2O-N. This range encompasses more than 90 per cent of the field emission values published at the time. The default emission factors for direct emissions of N_2O for Europe are:

EF_1 (fraction of N-input, kg N_2O-N/kg N) = 0.0125 (0.0025-0.0225)
EF_2 (kg N_2O-N/ha/yr) = 8 (2-15) - updated from figure of 5 in IPCC 1996 revised guidelines (IPCC, 1997) by IPCC 2001 Good Practice Guidelines (IPCC, 2001).

Section A1.1.6. describes how these emission factors are used.

A1.1.1.2 Animal excreta nitrogen used as fertiliser

The following is taken from IPCC (1997). Although the amount of nitrogen used as fertiliser from animal excreta is more uncertain than the amount of synthetic fertiliser used, estimates can be made, based on animal population and agricultural practices. To account for the loss of fertiliser from NH_3 volatilisation and emission of nitric oxide (NO) through nitrification after fertiliser is applied to fields, NH_3 volatilisation and NO emission factors are needed. Even though climate, soil, fertiliser placement and type, and other factors influence NH_3 volatilisation and NO_X emissions, a default emission factor of 0.1 (kg NH_3–N + NO_X–N emitted/kg N applied) can be used for synthetic fertilisers and 0.2 (kg NH_3–N + NO_X–N emitted/kg N applied) for animal waste fertiliser (0.2 is used for animal waste because of the potentially larger NH_3 volatilisation). The amount of nitrogen from these sources available for conversion to N_2O is therefore equal to 90 per cent of the synthetic fertiliser nitrogen applied and 80 per cent of the animal waste nitrogen applied.

When calculating the losses of volatile N species within manure management, N_2 losses are important. The chapter in the EMEP/CORINAIR Emission Inventory Guidebook, which is being revised with regard to these emissions in the near future, will provide a methodology. The mass flow approach, which forms the base of these calculations, can be found in Dämmgen *et al*. (2003).

A1.1.1.3 Biological nitrogen fixation

Although the amount of nitrogen fixed by biological nitrogen fixation in agricultural systems can be estimated, the N_2O conversion coefficient is highly uncertain. Research indicates that biological nitrogen fixation (BNF) contributes more nitrogen for plant growth than the total amount of synthetic nitrogen fertilisers applied to crops each year. Cultivation of grain legumes, however, often results in net soil nitrogen depletion. Nitrogen from BNF may serve to fertilise an associated crop and eventually to stimulate N_2O formation. IPCC (1997) reviews studies indicating that legumes may contribute to N_2O emission in a number of ways. Atmospheric N_2 fixed by legumes can be nitrified and denitrified in the same way as fertiliser N, thus providing a source of N_2O. Additionally, symbiotically living Rhizobia in root nodules are able to denitrify and produce N_2O. Total nitrogen input is estimated by assuming that total crop biomass is about twice the mass of edible crop, and a certain nitrogen content of nitrogen fixing crop (FracNCRBF – see below). A residue/crop ratio of 1 is assumed.

A1.1.1.4 Crop residues

The following section is taken directly from IPCC (1997). There is only limited information concerning re-utilisation of nitrogen from crop residues and nitrogen from sewage sludge applied to agricultural lands. Although the amount of nitrogen that recycles into agricultural fields through these mechanisms may add 25-100 Tg of N/yr of additional nitrogen into agricultural soils (mainly from crop residues) the amount converted to N_2O is not known. To account for the N_2O in the inventory budget the emission factor for fertilisers is used as default and the amount of nitrogen re-entering cropped fields through crop residues is calculated from the FAO crop production data.

Nitrous oxide emissions associated with crop residue decomposition are calculated by estimating the amount of nitrogen entering soils as crop residue (FCR). The amount of nitrogen entering the crop residue pool is calculated from crop production data. Estimates of crop production (the edible part) must be roughly doubled to estimate total crop biomass. A nitrogen percentage ($Frac_{NCRBF}$ and $Frac_{NCR0}$ – see below) is then assumed to convert from kg dry biomass/yr to kg N/yr in crops. As a default N-fixing crops (pulses and soybeans) and non-N-fixing crops can be distinguished. Some of the crop residue is removed from the field as crop (approximately 45 per cent), and some may be burned (not in Europe), or fed to animals.

A1.1.1.5 Cultivation of high organic content soils

Large N_2O emissions occur as a result of cultivation of organic soils (Histosols) due to enhanced mineralisation of old, N-rich organic matter. The rate of N-mineralisation is determined by the N-quality of the Histosol, management practices and climatic conditions. The range for enhanced emissions of N_2O due to cultivation is estimated to be 2-15 kg N_2O-N/ha/yr of cultivated Histosol. IPCC Good Practice Guidance (2001) adopted a default emission value of 8 kg N_2O-N ha^{-1} yr^{-1} for temperate and boreal regions.

A1.1.1.6 The methodology for estimating direct N_2O emissions from agricultural fields

The *Revised IPCC 1996 Methodology* for assessing direct N_2O emissions from agricultural fields includes consideration of synthetic fertiliser (F_{SN}), nitrogen from animal waste (F_{AW}), enhanced N_2O production due to biological N-fixation (F_{BN}), nitrogen from crop residue mineralisation (F_{CR}) and soil nitrogen mineralisation due to cultivation of Histosols (F_{OS}).

In this estimate, the total direct annual N_2O-N emission is:

$$N_2O_{DIRECT} = [(F_{SN} + F_{AW} + F_{BN} + F_{CR}) \times EF_1] + F_{OS} \times EF_2 \qquad \text{(Eq. 1)}$$

where:

N_2O_{DIRECT} = direct N_2O emissions from agricultural soils in country (kg N/yr);
EF_1 = emission factor for direct soil emissions (kg N_2O-N/kg N input) (see section 3.1.1.1);
EF_2 = emission factor for organic soil mineralisation due to cultivation (kg N_2O-N ha/yr) (see section 3.1.1.1);
F_{OS} = area of cultivated organic soils within country (ha of histosols);
F_{AW} = manure nitrogen used as fertiliser in country, corrected for NH_3 and NOx emissions and excluding manure produced during grazing (kg N/yr);
F_{BN} = N fixed by N-fixing crops in country (kg N/yr);

F_{CR} = N in crop residues returned to soils in country (kg N/yr);
F_{SN} = synthetic nitrogen applied in country (kg N/yr);
F_{SN} =N_{FERT} x (1-$Frac_{GASF}$);
F_{AW} = (N_{ex} x (1-($Frac_{FUEL}$ + $Frac_{GRAZ}$ + $Frac_{GASM}$));
F_{BN} = 2 x $Crop_{BF}$ x $Frac_{NCRBF}$;
F_{CR} = 2 x [$Crop_0$ x $Frac_{NCR0}$ + $Crop_{BF}$ x $Frac_{NCRBF}$] x (1-$Frac_R$) x (1-$Frac_{BURN}$); and
N_{FERT} = synthetic fertiliser use in country (kg N/yr);

$Frac_{GASF}$ = fraction of synthetic fertiliser nitrogen applied to soils that volatilises as NH_3 and NO_X (kg NH_3-N and NO_X-N/kg of N input) (see below);
N_{ex} = amount of nitrogen excreted by the livestock within a country (kg N/yr);
$Frac_{FUEL}$ = fraction of livestock nitrogen excretion contained in excrements burned for fuel (kg N/kg N totally excreted)
$Frac_{GRAZ}$ = fraction of livestock nitrogen excreted and deposited onto soil during grazing (kg N/kg N excreted) country estimate;
$Frac_{GASM}$ = fraction of livestock nitrogen excretion that volatilises as NH_3 and NO_X (kg NH_3-N and NO_X -N/kg of N excreted) (see below);
$Crop_{BF}$ = seed yield of pulses + soybeans in country (kg dry biomass/yr);
$Frac_{NCRBF}$ = fraction of nitrogen in N-fixing crop (kg N/kg of dry biomass) (see below);
$Crop_0$ = production of all other (i.e., non-N fixing) crops in country (kg dry biomass/yr);
$Frac_{NCR0}$ = fraction of nitrogen in non-N-fixing crop (kg N/kg of dry biomass) (see below);
$Frac_R$ = fraction of crop residue that is removed from the field as crop (kg N/kg crop-N) (see below);
$Frac_{BURN}$ = fraction of crop residue that is burned rather than left on field (see below).

The default values for these parameters (as given by IPCC, 1997) for Europe are as follows. $Frac_{BURN}$ = 0.10 or less (kg N/kg crop-N), $Frac_R$ = 0.45 kg N/kg crop-N, FracFUEL = 0.0 kg N/kg N excreted, FracGASF = 0.1 kg NH_3-N + NO_X-N/kg of synthetic fertiliser N applied, FracGASM = 0.2 kg NH_3-N + NO_X-N/kg of N excreted by livestock, FracGRAZ (from figures on pasture, range and paddock), $Frac_{NCRBF}$ = 0.03 kg N/kg of dry biomass, $Frac_{NCR0}$ = 0.015 kg N/kg of dry biomass.

A1.1.2 Indirect N_2O emissions for nitrogen used in agriculture

Pathways for synthetic fertiliser and manure input that give rise to indirect emissions considered in the Revised 1996 IPCC guidelines for National Greenhouse Gas Inventories (IPCC, 1997) are volatilisation and subsequent atmospheric deposition of NH_3 and NO_X (originating from the application of fertilisers), nitrogen leaching and runoff and human consumption of crops followed by municipal sewage treatment. Not considered are emissions from the formation of N_2O in the atmosphere from NH_3 or from food processing. Since N_2O emissions from human consumption of crops followed by municipal sewage treatment are accounted for under the waste sector, they are not discussed further here.

A1.1.2.1 Atmospheric deposition of NO_X and NH_3

Atmospheric deposition of nitrogen compounds such as nitrogen oxides (NO_X) and ammonium (from NH_3) fertilise soils and surface waters and as such enhance biogenic N_2O formation. The IPCC (1997) reports rates of N_2O emissions are between 0.002 and 0.016 kg N_2O–N/kg of the amount of nitrogen deposited onto soils which is within the range of emission factors suggested for synthetic fertilisers. Emissions (EF4) are calculated as 0.01 (0.002-0.02) kg N_2O-N /kg of NO_X-N and NH_3-N emitted annually within a country.

Although climate and fertiliser type (e.g., urea or ammonium sulphate) may influence ammonia volatilisation, the IPCC (1997) use default values for NH_3 and NO_X volatilization of 0.1 kg nitrogen/kg synthetic fertiliser nitrogen applied to soils and 0.2 kg nitrogen/kg of nitrogen excreted by livestock ($Frac_{GASF}$ and $Frac_{GASM}$; see section 3.1.1.6).

A.1.2.2 Leaching and Runoff

A considerable amount of fertiliser nitrogen is lost from agricultural soils through leaching and runoff. The leached/runoff nitrogen enters groundwater, riparian areas and wetlands, rivers and eventually the coastal ocean. Fertiliser nitrogen in ground water and surface waters enhances biogenic production of N_2O as the nitrogen undergoes nitrification and denitrification.

The fraction of the fertiliser and manure nitrogen lost to leaching and surface runoff ($Frac_{LEACH}$) may range from 0.1-0.8. A default value of 0.3 is proposed by IPCC (1997) Total nitrogen excretion is used (Nex) in order to include manure produced during grazing.

$$N_{LEACH} = [N_{FERT} + N_{EX}] \times Frac_{LEACH} \qquad \text{(Eq. 2)}$$

The sum of the emission of N_2O due to N_{LEACH} in: 1) groundwater and surface drainage (EF_{5-g}), 2) rivers (EF_{5-r}), and 3) coastal marine areas (EF_{5-e}) is calculated to obtain the N_2O emission factor (EF_5) for N_{LEACH} . The total amount of nitrogen eventually denitrified remains the same but some is denitrified in riparian area and wetlands before the nitrogen reaches the ocean. Default parameter values for indirect emission factors (IPCC, 1997) for Europe are as follows: $Frac_{NPR}$ = 0.16 kg N/kg of protein, $Frac_{LEACH}$ = 0.3 (0.1-0.8) kg N/kg of fertiliser or manure N.

Groundwater: Assuming that all N_{LEACH} is in the form of nitrate, the IPCC recommends a default emission factor of 0.015 ($EF_{5–g}$; range 0.003-0.06) for N_2O from N_{LEACH} in groundwater and drainage ditches. The amount of N_2O emitted from groundwater (by upward diffusion or following entry of groundwater into surface water through rivers, irrigation, and drinking water) and agricultural drainage water is then estimated as:

$$N_2O \text{ from groundwater and agricultural drainage water} = N_{LEACH} \times EF_{5-g} \qquad \text{(Eq. 3)}$$

where $EF_{5–g}$ = 0.015 kg N_2O-N/kg N_{LEACH} , assuming that all N_2O produced in a particular year is emitted during that year.

Rivers: Once N_{LEACH} from groundwater and surface water enters rivers, additional N_2O is produced associated with nitrification and denitrification of N_{LEACH}. The IPCC (1997) method assumes that all N_{LEACH} entering rivers is nitrified once during river transport. The N_2O yield (moles N_2O-N/mol of NO_3-N) during nitrification is assumed to 0.003 for nitrification. For denitrification, a constant ratio of 0.005 for N_2O-N emission to denitrification (N_2–N production) in rivers is suggested. In summary, the emission factor for N_{LEACH} in rivers due to nitrification and denitrification [EF_{5-r}] is thus equal to 0.005 x N_{LEACH} [for nitrification] plus 0.005 x (N_{LEACH} /2) [for denitrification], or 0.0075 x N_{LEACH}. Therefore, N_2O-N produced from N_{LEACH} during river transport = N_{LEACH} x (EF_{5-r}), where EF_{5-r} = 0.0075.

Estuaries: Half of N_{LEACH} is assumed to be removed by denitrification in rivers in the form of N_2 and N_2O. The remaining 50 per cent of N_{LEACH} is discharged by rivers to estuaries. Nitrogen inputs to estuaries can undergo nitrification and denitrification, with associated N_2O production. For nitrification, the IPCC (1997) method assumes that half of the rivers inputs of N_{LEACH} are nitrified again in estuaries, and that the ratio of N_2O-N to NO_3–N produced is 0.005, as for rivers. For denitrification, it is assumed that 50 per cent of the N_{LEACH} that is carried to estuaries by rivers is denitrified, and the ratio of N_2O-N to denitrification (N_2-N) emitted is 0.005, as for rivers. In summary, it is assumed that 1) half of the N_{LEACH} is transported to estuaries by rivers, 2) half of the N_{LEACH} in estuaries is nitrified again in the estuary with a ratio of N_2O-N to NO_3-N of 0.005, and 3) half of the N_{LEACH} in estuaries is denitrified in the estuary with a N_2O-N to denitrification (N_2-N) ratio of 0.005. Therefore, N_2O-N produced from N_{LEACH} in estuaries = N_{LEACH} x (EF_{5-e}) where EF_{5-e} = 0.0025. The combined emission factor [EF_5] for N_2O due to N_{LEACH} in: 1) groundwater and surface drainage (EF_{5-g} = 0.015 kg N_2O-N/kg N_{LEACH}), 2) rivers (EF_{5-r} = 0.0075 kg N_2O-N/kg N_{LEACH}), and 3) coastal marine areas (EF_{5-e} = 0.0025 kg N_2O-N/kg N_{LEACH}) is 0.025 (EF_5). Therefore:

$$N_{LEACH} = [N_{FERT} + N_{ex}] \times Frac_{LEACH} \text{ and } N_2O(L) = N_{LEACH} \times EF_5 \qquad \text{(Eq. 4)}$$

where the default values are $Frac_{LEACH}$ = 0.3 kg N/kg N input to soils and EF_5 = 0.025 kg N_2O-N/kg N_{LEACH}.

A1.2 Methane

Only methane emissions from rice paddies are considered in IPCC guidelines but the new IPCC Good Practice Guidance for Land Use Change and Forestry (IPCC, 2004), considers that “the reduction of the CH_4 sink by fertilization should be reported”. Described here is the guidance from the IPCC 1996 Revised Guidelines (IPCC, 1997). Methane emissions from croplands can occur from rice fields. The area of rice grown in Europe is small and occurs mainly in southern Europe. All rice cultivated in Europe is assumed to be irrigated (IPCC, 1997). The information in this section is taken directly from Chapter 4 of the Revised 1996 IPCC guidelines for National Greenhouse Gas Inventories (IPCC, 1997). Emissions of methane from rice fields (IPCC, 1997) can be represented as follows:

$$Fc = EF \times A \times 10^{-12} \qquad \text{(Eq. 5)}$$

where:

Fc = estimated annual emission of methane from a particular rice water regime and for a given organic amendment, in Tg per year;
EF = methane emission factor integrated over cropping season, in g/m^2;
A = annual harvested area cultivated under conditions defined above. It is given by the cultivated area times the number of cropping seasons per year, i.e., in m^2/yr.

The seasonally integrated emission factor is evaluated from direct field measurements of methane fluxes for a single crop. In practice, it will be necessary to calculate the total annual emissions from a country as a sum of the emissions over a number of conditions. Total rice production can be divided into subcategories based on different biological, chemical and physical factors that control methane emissions from rice fields. In large countries, this may include different geographic regions. To account for the different conditions, F is defined as the sum of Fc (see Equation 5). This approach to emissions estimation can be represented as follows:

$$F = \Sigma_i \Sigma_j \Sigma_k EF_{ijk} \times 10^{-12} \qquad \text{(Eq. 6)}$$

where:

ijk are categories under which methane emissions from rice fields may vary.

For instance, i may represent water levels in the rice fields such as fields inundated for the duration of the growing season (flooded regime) or fields under water only intermittently. This occurs either under managed irrigation when water is not readily available or when rains do not maintain flooded conditions throughout the growing season (intermittent regime). j, k, may represent water regimes modified by other factors like organic inputs, soil textures, fertilisation regimes under each of the conditions represented by the index i, and so on. As more factors are identified, more categories need to be included. Inclusion of additional parameters should lead to an improvement of the estimate of the total emissions. The summation should include all cropping seasons.

The factors clearly identified by field experiments as being most important are (1) water regime with inorganic fertilisers (except sulphate-containing inorganic fertilisers which inhibit CH_4 production); (2) organic fertiliser applications; (3) soil type, and soil texture;
(4) cultivar; and (5) agricultural practices such as direct seeding or transplanting. Data show that in continuously flooded fields, some types of organic fertilisers and certain cultivars lead to higher emissions compared to rice grown without organic amendments or intermittent or managed irrigation in which the fields are not continuously inundated and only where chemical fertilisers are used. At present there are insufficient data to incorporate most of these factors. Nonetheless, the estimates can be improved substantially by incorporating the current knowledge on water regimes, organic amendments and soil types etc. For some countries the effects of organic fertiliser can be included.

National experts are encouraged to go beyond the basic method, and add as much detail as can be scientifically justified, based on laboratory and field experiments on various amendments and theoretical calculations, to arrive at the estimate of emissions from rice cultivation in their country. These details should be incorporated into subcategories (indices j,k in Equation 6) under each of the main water management categories in Equation 5 so that they can be compared at that level with data from other countries.

For example, where emission data are available for different fertiliser types, this may be incorporated into the calculations. Each category, (e.g., continuously flooded) would be further divided as follows:

F (continuously flooded) = F (flooded/mineral fertiliser) + F (flooded/organic amendment)

This procedure would then be repeated for as many separate subcategories as have been defined. Each amendment may be incorporated in the same manner.

Scaling factors (relative to emission factors for continuously flooded rice) for irrigated rice (all European rice production) are 1.0 for continuously flooded rice, 0.5 (0.2-0.7) for intermittently flooded rice with a single aeration and 0.2 (0.1-0.3) for intermittently flooded rice with multiple aeration. The seasonally integrated methane emission factor for the only European country (Italy) represented in the Revised 1996 IPCC guidelines for National Greenhouse Gas Inventories (IPCC, 1997) is 36 (17-54) g /m2. The arithmetic mean for all countries for which there are estimates is 20 (12-28) g /m2 (IPCC, 1997). This value is for soils ‘without organic amendments’. For conversion to methane emissions from soils ‘with organic amendments’, a default correction factor of 2 (range 2-5) is applied to the corresponding rice ecosystem for the ‘without organic amendment’ category.

A1.3 Carbon dioxide

Chapter 5 (section 5.3) of the Revised 1996 IPCC guidelines for National Greenhouse Gas Inventories (IPCC, 1997) describes the methods used to calculate CO_2 emissions and uptake by soils from land-use change and management.

The principal sources/sinks of CO_2 in soils are associated with changes in the amount of organic carbon stored in soils. The IPCC methodology aims to estimate net fluxes of CO_2 due to changes in soil organic carbon stocks. CO_2 releases from liming applications are also dealt with.

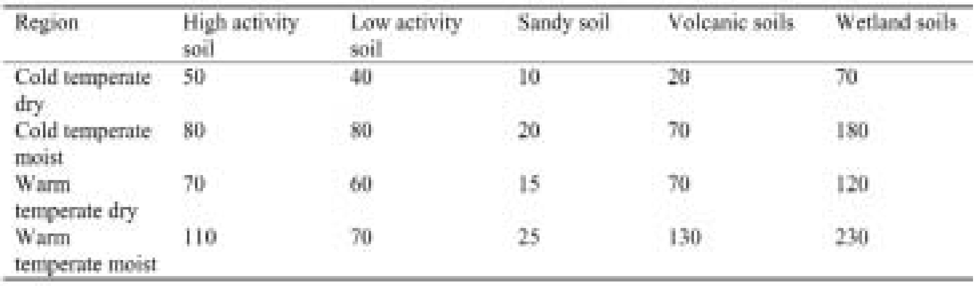
The IPCC (1997) method uses a stratification of up to six major soil groups, based on major differences in their inherent carbon stocks and their response to management. The soil groups are high clay activity mineral soils (e.g Vertisols, Chernozems, Phaeozems, Luvisols, Vertisols, Mollisols, high-base status Alfisols), low clay activity mineral soils (e.g. Acrisols, Nitosols, Ferralsols, Ultisols, Oxisols, acidic Alfisols), sandy soils (e.g. Arenosols, sandy Regosols Psamments), volcanic soils (e.g Andosols, Andisols), aquic (wet) soils (e.g. Gleysols Aquic suborders) and organic soils (Histosols). Of the climatic regions also used, all areas of Europe fall within the cool temperate dry, cool temperate moist, warm temperate dry or warm temperate moist zones. The method entails calculating changes in soil organic carbon stocks due to land clearing from native vegetation (any effects of land abandonment and shifting cultivation), tillage, and carbon inputs through residue management. Organic soils are dealt with separately.

The IPCC default methodology assumes a change in carbon stocks from one equilibrium level to another over a 20-year period and calculates changes for the 0-30cm horizon only. The calculation method for mineral soils is as follows:

$$\text{Soil Carbon}_{\text{managed}} = \text{Soil Carbon}_{\text{native}} \text{ x Base factor x Tillage factor x Input factors}$$

The base factors represent changes in soil organic matter associated with conversion of the native vegetation to agricultural use, as well as setting aside cropland from production. Tillage and input factors account for effects of various management practices of lands under agricultural use. Thus these later two factors can be used to capture the changes in management trends that have occurred over the inventory period. The tillage factor accounts for changing the intensity of tillage, ranging from the most intensive practices that fully invert the soil (often referred to as conventional tillage) to the least intensive practices, such as no-till (or zero tillage). The input factor captures changes in cropping rotations, intensities or use of organic amendments that ultimately affect the carbon input to the soil due to changing overall production. Default values for soil carbon levels under native vegetation (0-30 cm) are given in the table A1.3a.

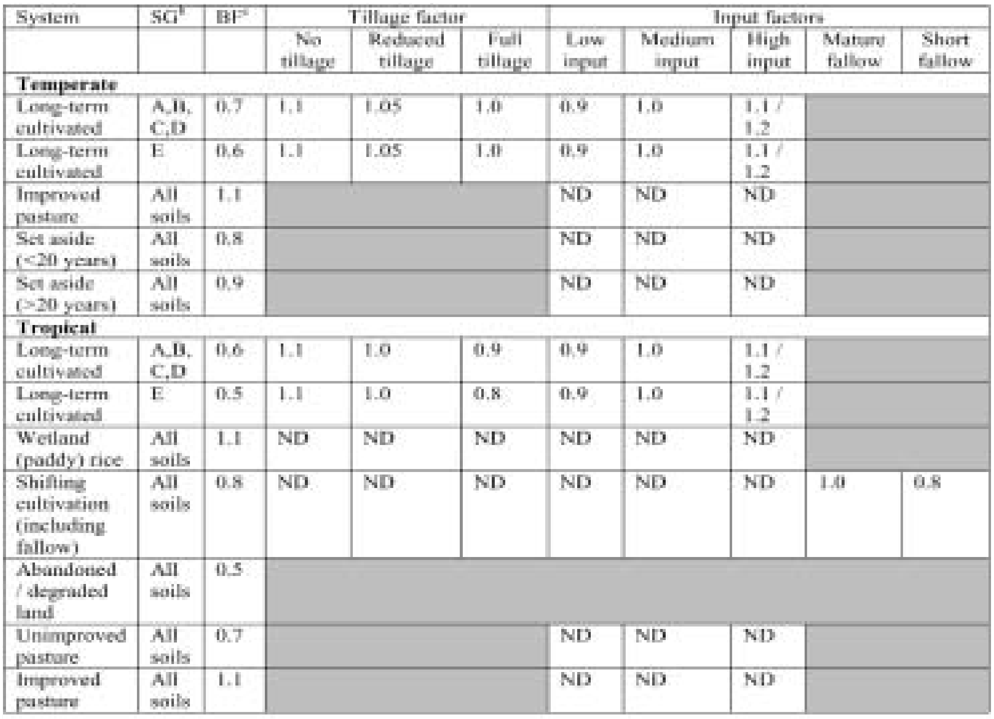
Table A1.3a. Approximate quantities of soil organic carbon under native vegetation (t C ha^{-1} to 0-30 cm depth; from IPCC, 1997) for climate zones found within Europe.



Region	High activity soil	Low activity soil	Sandy soil	Volcanic soils	Wetland soils
Cold temperate dry	50	40	10	20	70
Cold temperate moist	80	80	20	70	180
Warm temperate dry	70	60	15	70	120
Warm temperate moist	110	70	25	130	230

The coefficients used in the default calculations are shown in table A1.3b below.

Table A1.3b. Coefficients used in the IPCC default calculations estimating carbon stocks in mineral soils. Reproduced from IPCC (1997) [a].



System	SG[b]	BF[c]	Tillage factor			Input factors				
			No tillage	Reduced tillage	Full tillage	Low input	Medium input	High input	Mature fallow	Short fallow
Temperate										
Long-term cultivated	A,B, C,D	0.7	1.1	1.05	1.0	0.9	1.0	1.1 / 1.2		
Long-term cultivated	E	0.6	1.1	1.05	1.0	0.9	1.0	1.1 / 1.2		
Improved pasture	All soils	1.1				ND	ND	ND		
Set aside (<20 years)	All soils	0.8				ND	ND	ND		
Set aside (>20 years)	All soils	0.9				ND	ND	ND		
Tropical										
Long-term cultivated	A,B, C,D	0.6	1.1	1.0	0.9	0.9	1.0	1.1 / 1.2		
Long-term cultivated	E	0.5	1.1	1.0	0.8	0.9	1.0	1.1 / 1.2		
Wetland (paddy) rice	All soils	1.1	ND	ND	ND	ND	ND	ND		
Shifting cultivation (including fallow)	All soils	0.8	ND	ND	ND	ND	ND	ND	1.0	0.8
Abandoned / degraded land	All soils	0.5								
Unimproved pasture	All soils	0.7				ND	ND	ND		
Improved pasture	All soils	1.1				ND	ND	ND		

Notes:

a Filled portions of the table, where tillage and input factors are not given, denote instances where these factors are not applicable to a management system. Where tillage or input factors were not determined (ND), information was deemed insufficient to go beyond estimating a base factor. SG = Soil Group, BF = Base Factor

b Soil groups A = High activity, B = Low activity, C = Sandy, D = Volcanic, E = Aquic

c For temperate cultivated soils, the average loss of 30% (0.7) is based on studies reported in IPCC (1997). Greater losses for cultivation of wet (aquic) soils, relative to other mineral soils, are assumed due to artificial drainage and enhanced decomposition when cultivated. Conversion to paddy rice is assumed to slightly increase carbon contents. Carbon levels in improved pastures can exceed native levels with fertilisation and species selection. Carbon under shifting cultivation (including the fallow phase) and abandoned degraded lands are based on estimates reported in IPCC (1997)

d Use of no-till is assumed to increase soil carbon by 10% over full tillage (full soil inversion) in temperate systems, based on analysis of long-term experiments in Australia, Canada, Europe and the United States; greater effects, over full tillage, are assumed for tropical systems. Reduced tillage (i.e., significant soil disturbance but without inversion) is assumed to yield small increases over full tillage

e Input factors apply to residue levels and residue management, use of cover crops, mulching, agroforestry, bare fallow frequency in semi-arid temperate systems. Low input applies to where crop residues are removed or burned, or use of bare fallow; medium input to where crop residues are retained; high input applies to where residue additions are significantly enhanced with addition of mulches, green manure, or enhanced crop residue production (1.1) or regular addition of high rates of animal manure (1.2), relative to the nominal (medium) case. Based on studies reported in IPCC (1997).

For organic soils, the method is based on the assumption that there are constant loss rates for cropland due to drainage of wetlands, and that those rates vary with climate. Losses are 0.25 t C/ha/yr in cool temperate regions, 10 t C/ha/yr in warm temperate regions, and 20 t C/ha/yr in the tropical regions. The loss rates from conversions to pasture are 25 per cent of those under cropland within each climate region. For liming, for the purposes of the inventory it is assumed that the addition rate of lime is in near equilibrium to the consumption of lime applied in previous years. Emissions associated with use of carbonate limes can thus be calculated from the amount and composition of the lime applied annually within a country.

Total annual emissions of CO_2, are calculated from *i*) net changes in carbon storage in mineral soil, *ii*) CO_2-C emissions from organic soils and *iii*) CO_2-C emissions from liming.

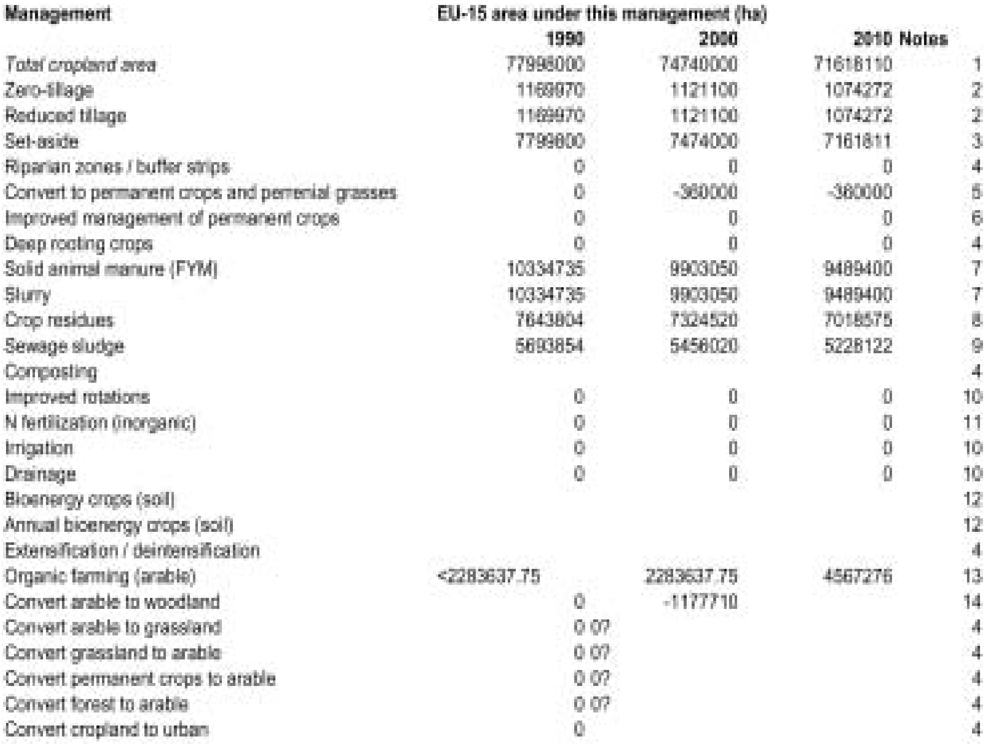
Appendix 2. Estimates and measurements of areas under different cropland management practices and assumptions made for EU-15 and four case study EU countries: UK, Sweden, Belgium and Finland.

This appendix gives the estimates and measurements of areas under given management practices and outlines any assumptions made. The areas are given for EU-15 and four case study EU countries: UK, Sweden, Belgium and Finland. The areas given here were multiplied by the per-area carbon sequestration rates for each management practice given in Table 5.1 to estimate the soil carbon cropland flux from each country / region examined. These estimates, expressed on the basis of t C ha cropland area^{-1} y^{-1} to allow different areas to be compared, are shown in Figures 5.3 and 5.4 in the main text.

A2.1 EU-15

The areas under each cropland management practice in the EU-15 for 1990, 2000 and 2010 are shown in table A2.1 below. The data sources and assumptions made are given in the notes.

Table A2.1 Areas under each cropland management practice in the EU-15



Management	EU-15 area under this management (ha)			
	1990	2000	2010	Notes
Total cropland area	77998000	74740000	71618110	1
Zero-tillage	1169970	1121100	1074272	2
Reduced tillage	1169970	1121100	1074272	2
Set-aside	7799800	7474000	7161811	3
Riparian zones / buffer strips	0	0	0	4
Convert to permanent crops and perrenial grasses	0	-360000	-360000	5
Improved management of permanent crops	0	0	0	6
Deep rooting crops	0	0	0	4
Solid animal manure (FYM)	10334735	9903050	9489400	7
Slurry	10334735	9903050	9489400	7
Crop residues	7643804	7324520	7018575	8
Sewage sludge	5693854	5456020	5228122	9
Composting				4
Improved rotations	0	0	0	10
N fertilization (inorganic)	0	0	0	11
Irrigation	0	0	0	10
Drainage	0	0	0	10
Bioenergy crops (soil)				12
Annual bioenergy crops (soil)				12
Extensification / deintensification				4
Organic farming (arable)	<2283637.75	2283637.75	4567276	13
Convert arable to woodland	0	-1177710		14
Convert arable to grassland	0 0?			4
Convert grassland to arable	0 0?			4
Convert permanent crops to arable	0 0?			4
Convert forest to arable	0 0?			4
Convert cropland to urban	0			4

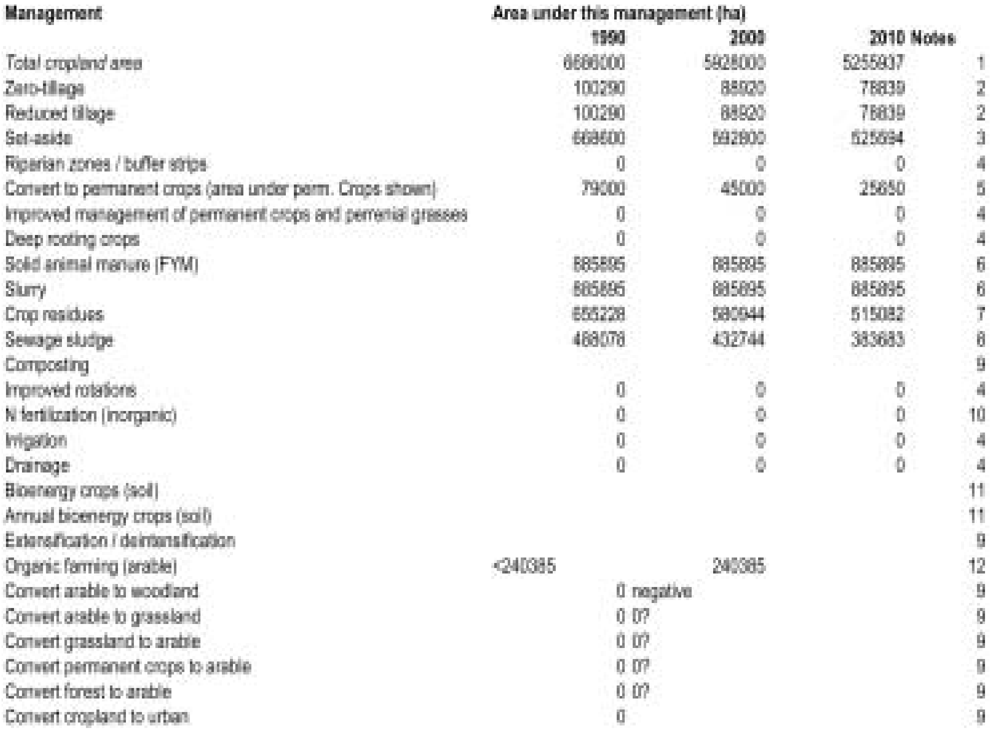
Notes:

1 = From FAO statistics for 1990 and 2000; same change 2000-2010 assumed as for 1990-2000, 2 = 1990 figure assumes 50:50 split of the reduced/no-till area; total = 3% of cropland (from Smith *et al.*, 2000a); assumed no change to 2000 as no incentives to increase reduced tillage so also assume no change to 2010, 3 = assume to be 10% of cropland (Smith *et al.*, 2000a), 4 = No data available, 5 = 2000 figure from Freibauer *et al*. (2004); assumed no change 2000-2010, 6 = Permanent crops only; no evidence for change since 1990, 7 = From Smith *et al.* (2000a) for 20 t dm ha^{-1} y^{-1}; assumed constant for 1990 to 2010; assume 50:50 slurry to solid FYM, 8 = From Smith *et al*. (2000) for 10 t dm ha^{-1} y^{-1}; assumed constant for 1990 to 2010, 9 = From Smith *et al*. (2000a) for 1 t dm ha^{-1} y^{-1}; assumed constant for 1990 to 2010, 10 = No evidence of any change, 11 = From FAO statistics there is a 30kg N ha^{-1} drop in fertilizer application rates 1990-2000 so the trend is away from increased fertilization; therefore assumed to be zero, 12 = Actual amounts are very small in 1990; assumed to negligible, 13 = Year 2000 figure is from FAO 2003 data; area (ha) under organic agriculture is scaled by 0.514 for conversion from UAA to cropland, 14 = Figures from Freibauer *et al*. (2004) which states that 37% of the new forest is from arable land.

A2.2 UK

The areas under each cropland management practice in the UK for 1990, 2000 and 2010 are shown in table A2.2 below. The data sources and assumptions made are given in the notes.

Table A2.2 Areas under each cropland management practice in the UK



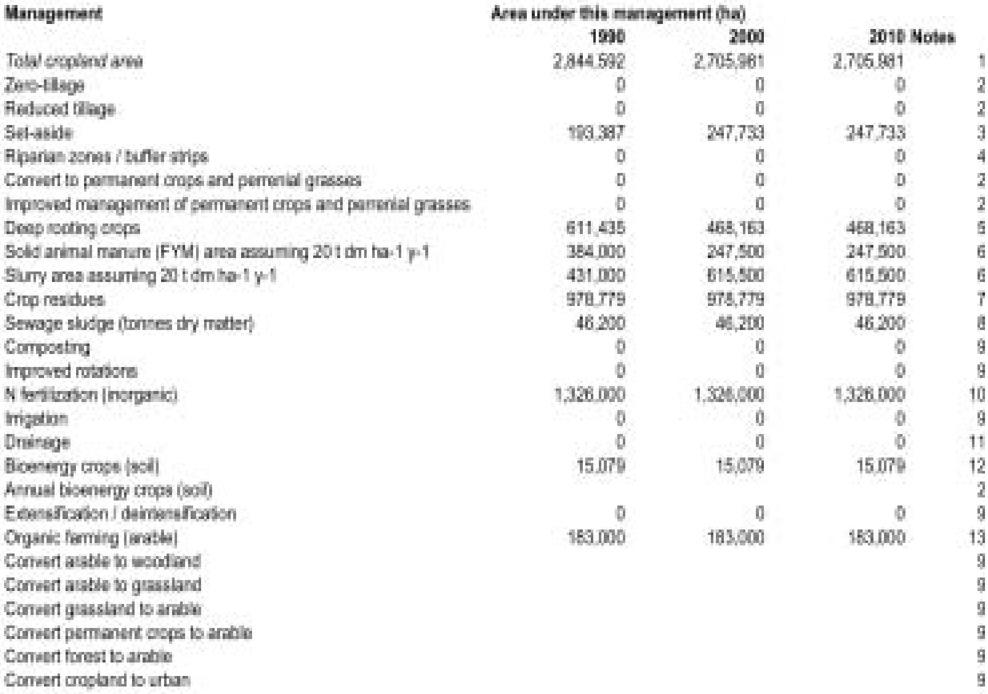
Management	Area under this management (ha)			
	1990	2000	2010	Notes
Total cropland area	6686000	5928000	5255937	1
Zero-tillage	100290	88920	78839	2
Reduced tillage	100290	88920	78839	2
Set-aside	668600	592800	525594	3
Riparian zones / buffer strips	0	0	0	4
Convert to permanent crops (area under perm. Crops shown)	79000	45000	25650	5
Improved management of permanent crops and perrenial grasses	0	0	0	4
Deep rooting crops	0	0	0	4
Solid animal manure (FYM)	885895	885895	885895	6
Slurry	885895	885895	885895	6
Crop residues	655228	580944	515082	7
Sewage sludge	468078	432744	383683	8
Composting				9
Improved rotations	0	0	0	4
N fertilization (inorganic)	0	0	0	10
Irrigation	0	0	0	4
Drainage	0	0	0	4
Bioenergy crops (soil)				11
Annual bioenergy crops (soil)				11
Extensification / deintensification				9
Organic farming (arable)	<240385	240385		12
Convert arable to woodland	0	negative		9
Convert arable to grassland	0	0?		9
Convert grassland to arable	0	0?		9
Convert permanent crops to arable	0	0?		9
Convert forest to arable	0	0?		9
Convert cropland to urban	0			9

Notes: 1 = FAO figures used for 1990 and 2000; for 2010 figures the same change for 2000-2010 as for 1990-2000 is assumed, 2 = The 1990 figure assumes a 50:50 split of the reduced/no-till area; total assumed to be 3% of cropland (Smith *et al*., 2000b); assumed no change to 2000 as no incentives to increase no till area so no change to 2010 is also assumed, 3 = Assume 10% of cropland (Smith *et al.*, 2000b,c), 4 = No evidence of significant change, 5 = Permanent crop area in UK in 1997 was 57% of what it was in 1990 - i.e. permanent crop area is decreasing; 2010 figures assume the same change for 2000-2010 as for 1990-2000, 6 = From Smith *et al*. (2000a, b) for 20 t dm ha^{-1} y^{-1}; assumed constant for 1990 to 2000 as cattle plus swine numbers in UK remain unchanged from 1990-1997 [difference of <0.6%; FAO statistics from EarthTrends, 2003]; assumed same level of manure available - as cropland area decreases, a larger proportion of area can be covered at same rate so we assume same area as in 1990 receives manure at 20t dm h^{-1} y^{-1}; same assumption for 2000-2010; 50:50 slurry to solid FYM assumed, 7 = From Smith *et al.* (2000a,b) for 10 t dm ha^{-1} y^{-1}: as cropland area decreases, cereal straw production also decreases in proportion; assumed constant % of available cropland for 1990 to 2010, 8 = From Smith *et al*. (2000a,b) for 1 t dm ha^{-1} y^{-1}; assumed constant for 1990 to 2010, 9 = No data, 10 = From FAO statistics (EarthTrends, 2003); there has been a 30 kg ha^{-1} decrease in fertilizer application rates 1990-2000 so the trend is away from increased N fertilization; therefore assumed to be zero, 11 = Actual amounts are very small in 1990; assumed to negligible,12 = The 2000 figure is from EarthTrends (2003: FAO statistics) as % of UAA in 2003 ([~4% of UK UAA] scaled by 0.3537 to get from UAA to cropland area in UK).

A2.3 Sweden

The areas under each cropland management practice in Sweden for 1990, 2000 and 2010 are shown in table A2.3 below. The data sources and assumptions made are given in the notes.

Table A2.3 Areas under each cropland management practice in Sweden



Management	Area under this management (ha)			
	1990	2000	2010	Notes
Total cropland area	2,844,592	2,705,981	2,705,981	1
Zero-tillage	0	0	0	2
Reduced tillage	0	0	0	2
Set-aside	193,387	247,733	247,733	3
Riparian zones / buffer strips	0	0	0	4
Convert to permanent crops and perrenial grasses	0	0	0	2
Improved management of permanent crops and perrenial grasses	0	0	0	2
Deep rooting crops	611,435	468,163	468,163	5
Solid animal manure (FYM) area assuming 20 t dm ha-1 y-1	384,000	247,500	247,500	6
Slurry area assuming 20 t dm ha-1 y-1	431,000	615,500	615,500	6
Crop residues	978,779	978,779	978,779	7
Sewage sludge (tonnes dry matter)	46,200	46,200	46,200	8
Composting	0	0	0	9
Improved rotations	0	0	0	9
N fertilization (inorganic)	1,326,000	1,326,000	1,326,000	10
Irrigation	0	0	0	9
Drainage	0	0	0	11
Bioenergy crops (soil)	15,079	15,079	15,079	12
Annual bioenergy crops (soil)				2
Extensification / deintensification	0	0	0	9
Organic farming (arable)	183,000	183,000	183,000	13
Convert arable to woodland				9
Convert arable to grassland				9
Convert grassland to arable				9
Convert permanent crops to arable				9
Convert forest to arable				9
Convert cropland to urban				9

Notes: 1 = SCB, Farms with more than 2 ha, including leys and grassland; assume 2010 same as 2000, 2 = No data given, 3 = SCB, 1990 including black fallow, green fallow and other not utilized land, 2000 black and green fallow; assume 2010 same as 2000, 4 = Included in set aside, 5 = SCB, winter cereals, sugar beet, rape oil seed included; assume 2010 same as 2000, 6 = SCB, data from 1991and 2001 respectively; in 2001 including all manures from "other animals"; areas calculated from dry matter tonnes assuming application rate of 20 t dm ha^{-1} y^{-1}. 7 = SCB, data only available from 1997; areas with incorporated crop residues; no other data so assume 1990 and 2010 same as for 2000, 8 = SCB; no other data so assume 1990 and 2010 same as for 2000, 9 = No data so assume none or no change, 10 = SCB data for 2001; no other data so assume 1990 and 2010 same as for 2000, 11 = In principle all arable land, 12 = SCB. Energy forest; no other data so assume 1990 and 2010 same as for 2000, 13 = SCB. 2002; no other data so assume 1990 and 2010 same as for 2000.

A2.4 Belgium

The areas under each cropland management practice in Belgium for 1990, 2000 and 2010 are shown in table A2.4 below. The data sources and assumptions made are given in the notes.

Table A2.4 Areas under each cropland management practice in Belgium

Management	**Area under this management (ha)**			
	1990	**2000**	**2010**	**Notes**
Total cropland area	724240	748657	748657	1
Zero-tillage	0	12372.5	24745	2
Reduced tillage	0	12372.5	24745	2
Set-aside	1478	23549	27750	3
Riparian zones / buffer strips	0	0	10680	4
Convert to permanent crops and perrenial grasses	0	0	0	5
Improved management of permanent crops and perrenial grasses	12310	17326	17326	6
Deep rooting crops	0	0	0	5
Solid animal manure (FYM)	0	241000	122000	7
Slurry	0	81168.8	41089.6	8
Crop residues	0	0	0	9
Sewage sludge	13500	0	0	10
Composting	1275	14125	14125	11
Improved rotations	5240	4498	101917	12
N fertilization (inorganic)	0	0	0	13
Irrigation	25690	25690	25690	14
Drainage	75594	75594	75594	14
Bioenergy crops (soil)	0	10000	10000	15
Annual bioenergy crops (soil)	0	10000	10000	15
Extensification / deintensification	0	0	0	16
Organic farming (arable)	715	9900	16500	17
Convert arable to woodland	658	308	5900	18
Convert arable to grassland	53	1421	1421	19
Convert grassland to arable	0	0	0	5
Convert permanent crops to arable	0	0	0	5
Convert forest to arable	0	0	0	5
Convert cropland to urban	233	398	398	19

Notes: 1 = Cropland assumed to be the same in 2010 as in 2000, 2 = The total for no till and reduced till (49490 ha) is assumed to be split 50:50 between zero and reduced till, assuming adoption over 20 years for suitable soils (>18 % clay and non hydromorphous; Arrouays *et al.*, 2002); also assume 2000 value is mid way between 1990 and 2000 value, 3 = 1990 and 2000 INS data; set-aside rose sharply in the early 1990s as a result of the CAP reforms and is currently fluctuating; estimates for 2010: 10% of the 2000 cereal area, 4 = For 2010, the Walloon region gives subsidies for a max of 8% of the cultivated area under the headland conservation scheme; we assume again an uptake rate of 0.35, 5 = No data, 6 = 1990 and 2000 INS data for the surface of orchards; nearly all orchards have grass strips (assume 2010 same as 2000), 7 = FYM production 10.14 Tg dm (1990); 10.44 Tg dm (2000); Tg dm based on animal numbers, FYM production, type of housing, time spent in housing (Dendoncker *et al.*, 2003); for 2010 we assume a reduction of 25 % of the dairy cow numbers and 55% of the calves (0-24 months) based on EU regulations (Van Steertegem *et al.* 2000: Mira S 2000 page 189): FYM production 5.73 Tg dm (2010), 8 = Slurry production 2.34 Tg dm (1990); 2.25 Tg dm (2000); Tg dm based on animal numbers, slurry production, type of housing, time spent in housing (Dendoncker *et al.*, 2003); For 2010 we assume a reduction of 25 % of the dairy cow numbers and 55% of the calves (0-24 months) based on EU regulations (MIRAS 2000 page 189); slurry production 1.93 Tg dm (2010), 9 = There is an import of straw for animal bedding: 1.18 Tg (1990) and1.14 Tg (2000) cereal straw produced and 2.80 Tg (1990) 2.77 Tg (2000) required for bedding based on requirements per animal, time spent in housing and type of housing (Dendoncker *et al.*, 2003), 10 = Sewage sludge is only spread in the Walloon region; 90% is applied to arable land, however it is expected that the spreading will soon be forbidden, 11 = Based on Flanders: 75 k t waste composted in 1991 and 675 kt in 1998, Walloon region 156 k t waste in 1998. We assume that 1 kg waste produces 0.17 kg DM compost (Kiely 1997 page 661) and application rates of 10 Mg DM /ha, 12 = 1990 and 2000 INS (winter rapeseed): For 2010 we assume a maximum calculated as follows: the whole area of winter cereals to include a cover crop and maize in the Walloon region to be under-sown with grass over an adoption period of 20 years i.e. 35% of the area (Dendoncker *et al.*, 2003); subsidies for cover crops are available in both regions, whereas subsidies for maize are restricted to the Walloon region, 13 = All agricultural land is fertilised: N fertilisers decreased from 125 kg/ha in 1990 to 115 kg/ha in 1995 so trend away from increased fertilization; assume zero, 14 = INS 2000 data: this is the area that can be irrigated using the available equipment. We assume that cropland is irrigated and not grassland and assume 2010 same as for 2000. Since there is no evidence of a change between 1990 and 2000, 1990 values assumed to be the same as 2000, 15 = INS 2000: rapeseed for the production of non-alimentary oil in 1994 for the Walloon region 2010: Flemish and Walloon policies; assuming 50% annual crops and 50% perennial crops; 1990 values assumed to be the same as 2000, 16 = Probably not relevant in the Belgian context since less intensive systems will convert to organic farming (see note 17), 17 = Based on overall areas of organic farming, assuming a ratio of 0.55 cropland and 0.45 grassland (same as for conventional farming) (Dendoncker *et al.*, 2003). This could be an overestimation for 2000 since extensive cattle breeding converted first to organic farming, 18 = 1990 and 2000 from INS; For 2010; 6300 refers to the EU 'on farm woodland' scheme. 5500 to Flemish policies (10000 ha by 2020) assuming reforestation of 0.55 arable and 0.45 grassland for Flanders. The mean of this figure is used here, i.e. 5900 ha, 19 = 1990 and 2000 from INS; land used for non agricultural purposes (280 220)

A2.5 Finland

The areas under each cropland management practice in Finland for 1990, 2000 and 2010 are shown in table A2.5 below. The data sources and assumptions made are given in the notes.

Table A2.5 Areas under each cropland management practice in Finland

Management	Area under this management (ha)			
	1990	2000	2010	Notes
Total cropland area	2088200	2005700	1842000	1
Zero-tillage	5000	30000	500000	2
Reduced tillage	5000	380,000		3
Set-aside	182800	181100	325000	4
Riparian zones / buffer strips	0	8874	17748	5
Convert to permanent crops and perrenial grasses	0	0	0	6
Improved management of permanent crops and perrenial grasses	0	0	0	7
Deep rooting crops	0	0	0	7
Solid animal manure (FYM)	327417.803	236067.9561	169968.9284	8
Slurry	139195.1682	129632.2211	120726.2282	8
Crop residues	2088200	2005700	1842000	9
Sewage sludge	12.95	3.02	0.703111765	10
Composting	0	0	0	7
Improved rotations	0	0	0	7
N fertilization (inorganic)	2081448	1858277	1659034	11
Irrigation	0	0	0	12
Drainage	85 %	86 %	90 %*	13
Bioenergy crops (soil)	0	5000	373,000	14
Annual bioenergy crops (soil)	0	3500	145,000	15
Extensification / deintensification	0	0	0	7
Organic farming (arable)	6752	147423	147423	16
Convert arable to woodland	8545	5762	3912.407646	17
Convert arable to grassland	0	0	0	7
Convert grassland to arable	0	0	0	7
Convert permanent crops to arable	7634*	0	0	18
Convert forest to arable	0	0	0	7
Convert cropland to urban	0	0	0	7

Notes: 1 = Finland Area of crops (ha) (including cereals and cultivated grass). Yearbook of Farm Statistics 2000 and 2001, (Utilised agricultural area in 2001 in Finland was 2216900 ha), Scenario: Expert judgement, National Expert: Heikki Lehtonen, MTT Agrifood Research Finland, 2 = Expert judgement, National Expert: Laura Alakukku, MTT Agrifood Research Finland, 3 = The area of reduced tillage (ha) in 2000. National Expert: Eila Turtola, MTT Agrifood Research Finland, 4 = Yearbook of Farm Statistics 2001, Scenario: Expert judgement, National Expert: Heikki Lehtonen, MTT Agrifood Research Finland, 5 = In 2002 the area of riparian zones was 4724 ha and the area of buffer strips was 4150 ha (if width of the strip is 3 m), National Expert: Eila Turtola, MTT Agrifood Research Finland, 6 = The area of green fallow was 134 072 ha in 1995, 111 678 ha in 1999 and 121529 ha in 2002. National Expert: Eila Turtola, MTT Agrifood Research Finland, 7 = No data available, 8 = Total N in manure divided by the maximum allowed application rate (kgN ha-1); 2010 figure assumes same change 2000-2010 as for 1990-2000, 9 = Residues mostly left on soil, 10 = Total N in sludge divided by the maximum allowed application rate, 11 = Total cultivated area minus area of organic farming, 12 = Irrigation is very rare in Finland, 13 = Yearbook of farm statistics 2002, *Expert judgement, National Expert: Aulis Ansalehto [according to Laikari (1989)], 14 = Leinonen *et al.* (2003); reed canary grass for solid fuel, forage crops grown for biogas, spring turnip rape for diesel fuel, cereal for fuel ethanol (cereal straw harvested from 200 000 hectares excluded from scenario), 15 = Leinonen *et al.* (2003); spring turnip rape for diesel fuel, cereal for fuel ethanol, 16 = Yearbook of farm statistics 1998 and yearbook of farm statistics 2002; assumed stays same as for 2000, 17 = Finnish Statistical Yearbook of Forestry 2002; 2010 figure assumes same change 2000-2010 as for 1990-2000, 18 = Area converted to arable was 10088 ha in 2000 (Ministry of Agriculture and Forestry).It is not known whether this area comes from permanent crops, abandoned land, peatlands or other forms of land-use.* = Yearbook of farm statistics.

• Appendix 3. List of participants & contact details

IPCC National Greenhouse Gas Inventories Programme

Dr. Leandro Buendia
Programme Officer
IPCC National Greenhouse Gas Inventory Programme
Technical Support Unit - c/o Institute for Global Environmental Strategies
2108-11 Kamiyamaguchi, Hayama, Kanagawa
240-0115
Japan
Tel: +81-468-55-3750
Fax: +81-468-55-3808
E-mail: buendia@iges.or.jp

UNECE Task Force on emission inventories and projections TFEIP

Mr. Ulrich Dämmgen
Federal Agriculture Research Center
Institute of Agroecology
Bundesallee 50
D-38116 Braunschweig
Germany
Tel : +49 531 596 2601
Fax: +49 531 596 2599
e-mail : ulrich.daemmgen@fal.de

UNFCCC

Mr. Stelios Pesmajoglou
Climate Change Secretariat
UNFCCC
PO Box 260 124
D-53153 Bonne
Germany
e-mail : rocio.lichte@unfccc.int

European Commission

Dr. Claus Brüning
European Commission - DG Research
Environment and Sustainable Development Program
LUX 2/93
Rue de la Loi 200 - 1040 Brussels
Belgium
Tel.: +32 2 2954484
Fax: +32 2 2963024
e-mail: claus.bruning@cec.eu.int

Dr. Roland Hiederer
Institute for Environment and Sustainability
Joint Research Centre
TP 280 Ispra (VA)
I-21020
Italy
Tel: +39 0332 786 330
Fax: +39 0332 786 394
e-mail : roland.hiederer@jrc.it

Dr. Adrian Leip
Institute for Environment and Sustainability
Joint Research Centre
TP 280 Ispra (VA)
I-21020
Italy
Tel: +39 0332 786327
Fax: +39 0332 785022
e-mail : adrian.leip@jrc.it

Austria

Prof. Alexander Cernusca
Institute of Botany
University of Innsbruck
Sternwartestr. 15
6020 Innsbruck
Austria
Tel: +43-512-5075922
Fax: +43-512-5072975
email: Alexander.Cernusca@uibk.ac.at

Belgium

Dr. Ivan Janssens
Dept. Biology
Universiteit Antwerpen (UIA)
Universiteitsplein 1
B-2610 Wilrijk
Belgium
Tel : +32-3-820.22.55
Fax : +32-3-820.22.71
email: ivan.janssens@ua.ac.be

Prof. Dr. Oswald Van Cleemput
Faculty of Agricultural and Applied Biological Sciences
University of Ghent
Coupure 653
B-9000 Gent
Belgium
Tel: +32 9 2646002
Fax: +32 9 2646242
e-mail: Oswald.Vancleemput@rug.ac.be

Dr. Pascal Boeckx
Faculty of Agricultural and Applied Biological Sciences

University of Ghent
Coupure 653
B-9000 Gent
Belgium
Tel: +32 9 2646002
Fax: +32 9 2646242
e-mail: Pascal.Boeckx@rug.ac.be

Prof. Bas van Wesemael
Geography Department - Universite
Catholique de Louvain
Place Louis Pasteur 3
B-1348 Louvain-la-Neuve
Belgium
Tel: +32 10 472056
Fax: +32 10 472877
e-mail : vanwesemael@geog.ucl.ac.be

Columbia

Dr. María Cristina Amézquita
Project Scientific Director
Apartado Aéreo No. 67-13
Cali
Colombia
Tel: +57(2)4450000
Fax: +57(2)4450073
e-mail : m.amezquita@cgiar.org

Denmark

Dr. Kim Pilegaard
Risø National Laboratory
Plant Research Department
P.O. Box 49
DK-4000 Roskilde
Denmark
Tel : +45 4677 4175
Fax: +45 4677 4160
e-mail : kim.pilegaard@risoe.dk

Dr. Per Ambus
Risø National Laboratory
Plant Research Department
P.O. Box 49
DK-4000 Roskilde
Denmark
Tel : +45 4677 4152
Fax: +45 4677 4160
e-mail : per.ambus@risoe.dk

Dr. Jørgen E. Olesen
Danish Institute of Agricultural Sciences
(DIAS)
Dept. Agroecology
P.O. Box 50
DK-8830 Tjele
Denmark
Tel: +45 89991659
Fax: +45 89991619
e-mail: JorgenE.Olesen@agrsci.dk

Dr. Søren O. Petersen
Danish Institute of Agricultural Sciences
(DIAS)
Dept. Agroecology
P.O. Box 50
DK-8830 Tjele
Denmark
Tel: +45 8999 1723
Fax: +45 8999 1619
e-mail soren.o.petersen@agrsci.dk

France

Dr. Pierre Stengel
INRA - Direction Scientifique
Environnement - Ecosystèmes Cultivés et
Naturels (ECONAT)
147, rue de l'Université
75338 Paris cedex 07
France
Tél : +33 1.42.75.92.43 - à Avignon : +33
4.32.72.22.30
Fax : +33 1.42.75.94.49 à Avignon : +33
4.32.72.22.32
E-mail : stengel@paris.inra.fr

Dr. Bernard Seguin
INRA Avignon
Agroclim Unit - Mission ' Global Changing
and Greenhouse effect'
Site Agroparc
Domaine Saint-Paul
F-84914 Avignon Cedex 9
France
Tel : +33 (0)4 32 72 23 07
Fax: +33 (0)4 32 72 23 62
email : seguin@avignon.inra.fr

Dr. Dominique Arrouays
INRA Orléans
Director of the Infosol UNit
Avenue de la Pomme de Pin
BP 20619 Ardon
45166 Olivet cedex
France
Tel +33 (0)2 38414802
Fax +33 (0)238417869
e-mail : arrouays@orleans.inra.fr

Dr. Pierre-Alain Jayet
INRA Grignon
UMR INRA-INA PG - Public Economy
78850 Thiverval-Grignon
France
Tel. 01 30 81 53 49
Fax: 01 30 81 53 68
e-mail : Pierre-Alain.Jayet@grignon.inra.fr

Dr. Jean-François Soussana
INRA Clermont
Agronomy Unit
234, avenue du Brezet
63039 Clermont-Ferrand Cedex 02
France
Tel : +33 (0)473 62 44 23
Fax : +33 (0)473 62 44 57
e-mail : soussana@clermont.inra.fr

Ir. Sloan Saletes
INRA Clermont
Agronomy Unit
234, avenue du Brezet
63039 Clermont-Ferrand Cedex 02
France
Tel : +33 (0)473 62 44 25
Fax : +33 (0)473 62 44 57
e-mail : sloan.saletes@clermont.inra.fr

Dr. Pierre Loiseau
INRA Clermont
Agronomy Unit
234, avenue du Brezet
63039 Clermont-Ferrand Cedex 02
France
Tel : +33 (0)473 62 44 22
Fax : +33 (0)473 62 44 57
e-mail : loiseau@clermont.inra.fr

Dr. Pierre Cellier
INRA Grignon
UMR INRA-INA PG - Environment &
Arable Crops Unit
78850 Thiverval - Grignon
France
Tel. 01 30 81 55 32
Fax: 01 30 81 55 63
e-mail : Pierre.Cellier@bcgn.grignon.inra.fr

Dr. Jean-Pierre Jouany
INRA Clermont
Herbivores Unit
Site de Theix
63122 Saint-Genès-Champanelle
France
Tel. 04 73 62 40 54
Fax: 04 73 62 46 59
e-mail : Jean-
Pierre.Jouany@clermont.inra.fr

Dr. Nicolas Viovy
LSCE
Bât. 709
Orme des Merisiers
F-91191 Gif sur Yvette
France
Tel: +33 169 08 77 17
Fax: 169 08 77 16
e-mail : viovy@cea.fr

phD Nicolas Vuichard
LSCE
Bât. 709
Orme des Merisiers
F-91191 Gif sur Yvette
France
Tel: +33 169 08 77 24
Fax: +33 169 08 77 16
e-mail : vuichard@lsce.saclay.cea.fr

Ir. Sylvie Hacala
Institut de l'Elevage
9, rue André Brouard
49105 Angers Cedex 02
Tel : +33 02 41 18 61 74
Fax : +33 02 41 18 61 61
sylvie.hacala@inst-elevage.asso.fr

Ir. Jean-Louis Fiorelli
INRA SAD
Domaine du Joly
BP 29
88501 Mirecourt Cedex
France
Tel :+33 (0)3 29 38 55 12
Fax: +33 (0)3 29 38 55 19
e-mail : fiorelli@mirecourt.inra.fr

Germany

Dr. Hermann Jungkunst
Max-Planck-Institute for Biogeochemistry
P.O. Box 10 01 64
07701 Jena
Germany
e-mail: hermann@uni-hohenheim.de

Prof. Dr. Hans-Joachim Weigel
Dir.u.Prof.-Institutsleiter
Institut für Agrarökologie
Bundesforschungsanstalt für Landwirtschaft
(FAL)
Bundesallee 50
38116 Braunschweig
Germany
Tel: +49 531 596 2501
Fax: +49 531 596 2599
e-mail : hans.weigel@fal.de

Dr.-Ing. Achim Weiske
Institute for Energy and Environment
Torgauer Str. 116
D-04347 Leipzig
Germany
Tel: +49-341-2434-419
Fax: +49-341-2434-433
e-mail: weiske@ife-le.de

IRELAND

Dr. John Clifton-Brown
Trinity College
University of Dublin
Dublin 2
Ireland
Tel : +353 1-6081769
Fax : +353 1-6081147
e-mail : jcbrown@tcd.ie

Italy

Dr. Antonio Raschi
C.N.R. - I.Bi.Met
Piazzale delle Cascine 18
50144 Firenze
Italy
Tel: (39) 055-301422
Fax: (39) 055-308910
e-mail : a.raschi@ibimet.cnr.it

Dr. Erminia Sezzi
GHG Coordination Office
University of Tuscia
Laboratory of Forest Ecology
Via de Lellis 01100 Viterbo
Italy
Tel +39-0761-357394
Fax +39-0761-357389
e-mail : e.sezzi@unitus.it

Dr. Paolo Stefani
University of Tuscia
Laboratory of Forest Ecology
Via de Lellis 01100 Viterbo
Italy
Tel +39-0761-357394
Fax +39-0761-357389
e-mail: pstefani@unitus.it

The Netherlands

Dr. Oene Oenema
Wageningen University and Research Center
Alterra
P.O. Box 47
NL-6700 AA Wageningen
The Netherlands
e-mail Oene.Oenema@wur.nl

Dr. Peter (P.J.) Kuikman
Alterra - Green World Research
Dept. of Water and the Environment
Droevendaalsesteeg 3
P.O. Box 47
NL-6700 AA Wageningen
The Netherlands
Tel: +31.317.474334
Fax: +31.317.419000
e-mail: P.J.Kuikman@alterra.wag-ur.nl

Dr. A. (Jan) Verhagen
Plant Research International Business Unit
Agrosystems Research
P.O Box 16. 6700 AA Wageningen,
The Netherlands
Tel: 31 317 475945
Fax: 31 317 423110
e-mail : adrianus.verhagen@wur.nl

Ir. René (L.M.) Schils
PV - Research Institute for Animal Husbandry
Runderweg 6
8219 PK Lelystad Postbus 2176
8203 AD Lelystad
The Netherlands
Tel: 0320 - 293 211
Fax: 0320 - 241 584
e-mail : rene.schils@wur.nl

Dr. André van Amstel
Wageningen University - Environmental Systems analysis
PO Box 8080
6700 DD Wageningen
The Netherlands
Tel: +31 317 484812
Fax: +31 317 484839
e-mail : andre.vanamstel@wur.nl

Dr. Bram van Putten
Department of Mathematics and Statistics
Biometris, Wageningen University and Research Centre
P.O. Box 100, 6700 AC Wageningen
The Netherlands
Phone +31 317 483561
Fax +31 317 483554
e-mail : bram.vanputten@wur.nl

Dr. Frank Ewert
Plant Production Systems, Wageningen University
P.O. Box 430
6700 AK Wageningen
The Netherlands
Tel: + 31 - (0)317-484769
Fax: + 31 - (0)317-484892
e-mail: frank.ewert@wur.nl

Dr. ir. Peter A. Leffelaar.
Plant Production Systems, Wageningen University
P.O. Box 430
6700 AK Wageningen
The Netherlands
Tel : +31.317.483918 / 482141

Fax : +31.317.484892
e-mail: peter.leffelaar@wur.nl

Ir. Hans C. Willers
IMAG - Emissions and Environmental Innovations
Mansholtlaan 10-12, 6708 PA Wageningen
PO Box 43, 6700 AA Wageningen
The Netherlands
Tel: +31 (0) 317-47 65 91
Fax: +31 (0) 317-42 56 70
e-mail : hans.willers@wur.nl

Norway

Dr. Marit Lagreid
Hydro Agri Research Centre
P.O.box 2560
N-3907 Porsgrunn
Norway
Tel: +47 35923062
Fax: +47 35922327
e-mail : marit.lagreid@hydro.com

Sweden

Prof. Leif Klemedtsson
Department of Botany
Göteborg University
P.O. Box 461
SE-405 30 Göteborg
Sweden
Tel: +46 (0) 31 773 26 32
Fax: +46 (0)31
e-mail: leif.klemedtsson@botany.gu.se

Switzerland

Prof. Dr. Nina Buchmann
Institute of Plant Sciences
Universitätstrasse 2
ETH Zentrum LFW C56
CH-8092 Zuerich
Switzerland
Tel: +41-1-63-2 39 59
Fax: +41-1-63-2 11 53
e-mail: nina.buchmann@ipw.agrl.ethz.ch

Dr. Albrecht Neftel
Federal Research Station for Agroecology and Agriculture (FAL)
Air Pollution/Climate Group
P.O. Box
CH -8046 Zuerich
Switzerland
Tel: +41 1 377 7504
Fax: +41 1 377 7201
e-mail: albrecht.neftel@fal.admin.ch

Dr. Chris Flechard
Federal Research Station for Agroecology and Agriculture (FAL)
Air Pollution/Climate Group
P.O. Box
CH -8046 Zuerich
Switzerland
Tel: +41 1 377 7504
Fax: +41 1 377 7201
e-mail: chris.flechard@fal.admin.ch

UK

Dr. Bruce Ball
Scottish Agricultural College (SAC)
Crop and Soil Group - R & D Division
Bush Estate, Penicuik, Midlothian, EH26 0PH - U.K.
Tel : 0131 535 3048
Fax : 0131 535 3031
e-mail: b.ball@ed.sac.ac.uk

Dr. Pete Smith
Senior Lecturer in Soils & Global Change
School of Biological Sciences
University of Aberdeen
Cruikshank Building, St Machar Drive,
Aberdeen, AB24 3UU
U.K.
Tel: +44 (0)1224 272702
Fax: +44 (0)1224 272703
e-mail: pete.smith@abdn.ac.uk

Dr. Roland Harrison
Principal Research Scientist
ADAS Boxworth
Boxworth, Cambridge,
CB3 8NN, U.K.
Tel/Fax : 01284 735839
e-mail : Roland.Harrison@adas.co.uk

Dr. Celia Milford
Centre of Ecology and Hydrology
(Edinburgh Research Station)
Bush Estate, Penicuik
Midlothian, EH26 0QB
Scotland, UK
Tel : (44) 131 445 4343
Fax : (44) 131 445 3943
e-mail : cmil@ceh.ac.uk

USA

Dr. Stephen Ogle
Natural Resource Ecology Laboratory
Colorado State University
Fort Collins, CO 80523 - USA
Tele: 970-491-2104 - Fax: 970-491-1965
e-mail: ogle@nrel.colostate.edu