Agriculture

SNAP CODE: **100000**

SOURCE ACTIVITY TITLE: **AGRICULTURE: INTRODUCTORY REMARKS**

NOSE CODES: **Various**

NFR CODES: **Various**

1 OBJECTIVE

Section 10 of this Guidebook covers the core processes of arable and animal agriculture and structures them according to SNAP 97. This introduction aims at a compilation of the processes described, the gases or species emitted, and the methodology. It also indicates where processes, which are not described in this section, are dealt with in the Guidebook. Besides, it provides a definition that helps to differentiate agricultural and natural processes or sources.

The structure of the section reflects the reporting procedures rather than the calculation procedures. Therefore, it flags those peculiarities where reporting and calculation fall apart or where the calculation procedure requires data from a process covered by another chapter.

2 COVERAGE

Agriculture is a branch of industry which cultivates land and keeps animals in order to produce food, fodder or raw materials used for industrial processes, and comprises arable agriculture, animal agriculture, horticulture, viniculture, etc., with a wide range of intensities. In principle, a sharp distinction between agriculture and natural systems is impossible, as even these systems are used intentionally for food, fodder or animal production and – at least in Europe – are almost everywhere subject to management measures. In order to avoid double counting or omission of sources, we therefore define in accordance with Winiwarter et al. (1999) and Simpson et al. (1999) that **agriculture does not include**:

- Forest foliar emissions (even if the forests are heavily managed);
- Forest fire emissions;
- Natural grassland and other low vegetation, including lands used for grazing only (such as mountain sheep walks);
- Soils;
- Wetlands;
- Waters;
- Wild animals;
- Humans;
- Lightning;
- Volcanoes;
- Gas seeps.

In principle, **CO_2 emissions** from agricultural processes are not covered by this Guidebook section, as agriculture itself is considered neither a net source or sink. By definition, only the non-energy processes and breeding are covered. CO_2 emitting processes that relate to agriculture such as fertiliser production are dealt with in other sections (see below).

Guidebook chapters in section 10 deal with emissions of gases (Tables 1 and 2) and particles (Table 3) from various categories, which themselves are further **structured** with regard to the activities governing them. These activities are listed as in the SNAP coding, though this coding is not always consistent. The tables indicate which type of methodology is available in the respective Guidebook edition: **S**: Simpler methodology available; **D**: detailed methodology available. If information is provided to feed in national data rather then default data, the methodology is called “improved”, and the information “**I**” is given in the table.

Table 1: Classification of activities according to EMEP/CORINAIR (2001) and attribution to SNAP (2001): ***gases from arable agriculture***

Category	Activity	SNAP	NH_3	N_2O	NO	CH_4	nm VOC	PM	Remarks
Cultures with Fertilisers (Fertilised Agricultural Land)	Emissions from fertiliser N applied	10 01 00	**S, D**	**S**					
	Crop residues	10 01 00	**S**						
	Organic soils	10 01 00		**S**					
	Indirect emission from deposition	10 01 00		**S**	**S**				
	Indirect emission from leached N	10 01 00			**S**				
	Arable and grassland soils								
Cultures without Fertilisers	Legumes	10 02 00	**S**						
	Unfertilised grassland	10 02 00	**S**						
	Unfertilised agricultural soils	10 02 00		**S**	**S**				
Stubble Burning	On field burning of stubble, straw etc.	10 03 00	**S**					**S**	(1)
Pesticides and Limestone	Pesticides	10 06 00					**S**		
Natural Grasslands and other vegetation	Natural grasslands, crops	11 04 01					**S**		(2)

(1) The methodology allows calculation of NH_3-emissions with particles stemming from stubble burning only.

(2) These emissions have to be reported under 10 01!

Table 2: Classification of activities according to EMEP/CORINAIR (2001) and attribution to SNAP 97 (2001): ***gases from animal agriculture***

Category	Activity	SNAP	NH_3	N_2O	NO	CH_4	nm VOC	PM	Remarks
Methane emissions from animal husbandry (Enteric fermentation)	Dairy cows	10 04 01				**S**			(1)
	Other cattle	10 04 02				**S**			
	Sheep and goats	10 04 03							
	Fattening pigs	10 04 04							
	Horses	10 04 05							
	Sows	10 04 04							
	Sheep	10 04 05				**S**			
	Mules and asses	10 04 06				**S**			
	Goats	10 04 07							
	Laying hens	10 04 08							
	Broilers	10 04 09							
	Other poultry	10 04 10							
	Fur animals	10 04 11							
	Sows	10 04 12							
	Camels	10 04 13							
	Buffalo	10 04 14							
	Any other animals	10 04 15							
Manure management Regarding Organic Compounds	Dairy cows	10 05 01					**S**		(2)
	Other cattle	10 05 02					**S**		
	Fattening pigs	10 05 03					**S**		
	Sows	10 05 04					**S**		
	Sheep	10 05 05					**S**		
	Horses	10 05 06					**S**		
	Laying hens	10 05 07					**S**		
	Broilers	10 05 08					**S**		
	Other poultry	10 05 09					**S**		
	Fur animals	10 05 10					**S**		
	Goats	10 05 11							
	Mules and asses	10 05 12							
	Camels	10 05 13							
	Buffalo	10 05 14							
	Any other animals	10 05 11					**S**		
Manure management Regarding Nitrogen Compounds (3)	Dairy cows	10 09 01	**S, D**	**S**					
	Other cattle	10 09 02	**S, D**	**S**					
	Fattening pigs	10 09 03	**S, D**	**S**					
	Sows	10 09 04	**S, D**	**S**					
	Sheep	10 09 05	**S, D**	**S**					
	Horses	10 09 06	**S, D**	**S**					
	Laying hens	10 09 07	**S**	**S**					
	Broilers	10 09 08	**S, D**	**S**					
	Other poultry	10 09 09	**S, D**	**S**					
	Fur animals	10 09 10	**S**						
	Goats	10 09 11							
	Mules and asses	10 09 12							
	Camels	10 09 13	**S**						
	Buffalo	10 09 14	**S**						
	Any other animals	10 09 15							

(1) Methane emissions include both emissions from enteric fermentation and from manure management.

(2) Organic compounds comprise all organic compounds except CH_4, i.e. nmVOC.

(3) 10 09 SNAP has been reallocated in 2002, in line to changes to NFR. It now mirrors the 10 05 ordering.

Table 3: Classification of activities according to EMEP/CORINAIR (2001) and attribution to a preliminary SNAP code: ***particulate matter (primary particles) from agriculture and their constituents***

Category	Activity	SNAP	PM (mass)	Const. 1	Const. 2	....	....	....	Re-marks
Particulate matter	Housed livestock	10 10 00							
	Free range livestock	10 10 10							
	Feed management on farm	10 10 20							
	Plant production	10 10 30							

3 DETAILS – AGRICULTURAL EMISSIONS TO BE REPORTED IN GROUP 10

3.1 Subgroups 10 01 (cultures with fertilisers) and 10 02 (cultures without fertilisers)

Subgroups 10.01 and 10.02 are to be assigned all emissions (except those of CO_2) originating from the agricultural plants themselves or from their supporting soils.

As far as emissions from NO_x, N_2O and NH_3 are concerned, the basic difference between subgroups 10.01 and 10.02 is that for the latter only unintentional fertilisation is taken into account whilst for subgroup 10.01 both intentional as well as unintentional fertilisation are considered, each of these two categories being specified as follows:

Intentional fertilisation comprises:

- synthetic (mineral) fertiliser;
- natural inorganic fertiliser;
- organic manure (farmyard manure);
- compost (either from municipal solid waste or sewage sludge).

Note that NH_3 emissions from the plant/soil system which take place during and after spreading, are covered by chapter 10 90.

Unintentional fertilisation means:

- biological nitrogen fixation;
- manure excreted by grazing animals;
- N input with atmospheric deposition resulting from NO_x and NH_3 emissions from agricultural plants and soil; and
- crop residue application (this last category is defined to be unintentional for ease of emission estimation).

Note that indirect N_2O emissions due to N leaching/run-off from (intentional) fertilisation are calculated and reported under unintentional emissions in 10 02.
CH_4 emission generating activities are associated only with rice fields and described under codes 10 01 03 and 10 02 03.

CH_4 consumption (oxidation by methanotrophic soil micro-organisms) is not considered yet.

nmVOC emissions occur both in fertilised and unfertilised systems. In this Guidebook the algorithms the estimate them are given in chapter 11 04 (other sources and sinks) together with emissions from natural vegetation. However, they have to be reported under Cultures with fertilisers (10 01).

3.2 Subgroup 10 03 (on field burning of stubble, straw,...)

As suggested above this subgroup is proposed to cover all emissions originated from burning of agricultural vegetation-wastes, excluding those of agricultural non-vegetation wastes and also of wood wastes.

The methodology proposed in the IPCC Guidelines gives guidance for estimation emissions of NO_x, CH_4, CO and N_2O (and of CO_2 from C burnt). Nevertheless, emissions estimates could additionally be obtained for SO_2, nmVOC, and NH_3 using the methodology described in chapter 11 03 (forest fires) as the emissions factors for the latter three gases are there related to the mass of C burnt, per unit of residue mass burnt. The implied assumption in this methodological extension is that burning of agricultural wastes could be treated similarly to forest fires, at least for CH_4, CO and N_2O.

3.3 Subgroups 10 04 (Enteric fermentation) and 10 05 (Manure management regarding organic compounds)

In contradiction to the title of the chapter, CH_4 emissions both from enteric fermentation and from manure management are dealt with in this chapter. At present, only simpler methodologies are applied.

3.4 Subgroup 10 06 (Use of pesticides and limestone)

At present, a simpler methodology is given for the assessment of emissions from the application of pesticides only.

3.5 Subgroup 10 09 (Manure management regarding nitrogen compounds)

The subgroup deals with emissions of all gaseous nitrogen species (NH_3, N_2O, NO) from animal husbandry as a whole.

For NH_3, the calculation procedures given in this chapter include emissions from grazing animals, which have to be reported under 10 01 (Cultures with fertiliser). Note that grazing of “hill sheep” would have to be reported under 10 02 (Cultures without fertiliser), but (at present) the emission factor is zero. NH_3 emissions from manure and slurry applied to soil and plant canopies are to be reported under 10 09, whereas emissions of N_2O and NO from the same (physical) sources have to be reported under 10 01 (Cultures with fertilisers).

3.6 Subgroup 10 10 (Emissions of primary particles PM_{10}) [1]

Agricultural sources may emit particles directly. Both their size (particle diameter and shape) and the composition (element and species composition, active biological material such as bacteria) are interesting properties. In a first step, the chapter under preparation will deal with

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[1] The proposed SNAP 10 10 is new, created in 2001/02 in order to accommodate the need for reporting (under NFR) PM emissions from agricultural activities not yet covered by the existing SNAP definitions.

physical properties and classify particles accordingly (total suspended matter, TSP; particulate matter with an aerodynamic diameter < 10 µm, PM_{10}; particulate matter with an aerodynamic diameter < 2.5 µm, $PM_{2.5}$).

4 AGRICULTURAL ACTIVITIES NOT TO BE REPORTED IN GROUP 10

Sector specific emissions from agriculture or related to agriculture include sources which are not listed under chapter 10. These are covered in the Guidebook sections 02, 08 and 09.

4.1 Non-industrial combustion plants

A subgroup is reserved for all stationary combustion sources in the agriculture, forestry and aquaculture:

02 03	**Plants in agriculture, forestry and aquaculture**
02 03 01	Combustion plants >= 50 MW (boilers)
02 03 02	Combustion plants < 50 MW (boilers)
02 03 03	Stationary gas turbines
02 03 04	Stationary engines
02 03 05	Other stationary equipment

4.2 Non-industrial combustion plants

The internal combustion engines used in agriculture will be dealt with in a special subgroup.

08 06	**Agriculture**
08 06 01	2-wheel tractors
08 06 02	Agricultural tractors
08 06 03	Harvesters / combines
08 06 04	Others (sprayer, manure distributors, agricultural mowers, balers, tillers, swatchers)

At present, methods are given in chapter 08 10 00.

4.3 Non-industrial combustion plants

Though the title of section 09 is misleading, open burning of (organic) agricultural wastes with the exception of those items covered by 10 03 is dealt with in subgroup 09 07. A (very) simple methodology is given, which includes:

- Crop residues (cereals, crops, peas, beans, soy, sugar beet, oil seed rape etc.);
- Wood;
- Leaves;
- Animal carcasses (unless they are incinerated under controlled conditions, see Chapter 09 09 02);
- Plastics;
- Poultry and animal excreta (unless they are burnt under controlled conditions);
- Vegetation wastes except stubble, straw (covered within subgroup 10.03).

4.4 Other sources or sinks – agriculture under natural or semi-natural conditions

As mentioned above, extensive agriculture may make use of natural or semi-natural grassland or low vegetation, and is then to defined non-agricultural (see above).

11 04	**Natural grasslands and other vegetation**
11 04 01	Grassland
11 04 02	Tundra
11 04 03	Other Low vegetation
11 04 04	Other vegetation (Mediterranean scrub,…)

It is advisable that for the purpose of reporting definitions are made and justified in order to guarantee comparability of results.

5 NFR AND NOSE CODES

References are made to other codes used within the UNECE reporting system at the beginning of each chapter (at least when they are next updated). Besides, correspondence tables relating SNAP to IPCC and (at the same time) NFR coding are provided in Part B (Background), Chapter BSVI, of the Guidebook.

6 REFERENCES

Simpson D, Winiwarter W, Börjesson G, Cinderby S, Ferreiro A, Guenther A, Hewitt CN, Janson R, Khalil MAK, Owen S, Pierce TE, Puxbaum H, Shearer M, Skiba U, Steinbrecher R, Tarrasón L, Öquist MG (1999) Inventorying emissions from nature in Europe. J. Geophys. Res. 104, 8113-8152.

Winiwarter W, Haberl H, Simpson D (1999) On the boundary between man-made and natural emissions: Problems in defining European Ecosystems. J. Geophys. Res. 104, 8153-8159.

7 RELEASE VERSION, DATE AND SOURCE

Version: 1.0
Date: 1 July 2002

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SNAP CODE:	**100100** **100101** **100102** **100103** **100104** **100105**
SOURCE ACTIVITY TITLE:	**CULTURES WITH FERTILISERS** ***Permanent Crops*** ***Arable Land Crops*** ***Rice Field*** ***Market Gardening*** ***Grassland***
NOSE CODE:	**110.01.01** **110.01.02** **110.01.03** **110.01.04** **110.01.05**
NFR CODE:	**4 D 1** **4 C**

1 ACTIVITIES INCLUDED

This chapter considers the emissions of ammonia (NH_3), nitrous oxide (N_2O), other oxides of nitrogen (NO_x) and volatile organic compounds (VOCs) from agricultural soils to which nitrogen (N)-containing fertilisers are applied. Emissions from growing and decomposing fertilised plants are also included. Emissions following application of animal manures to land are considered in SNAP code 100500, Manure Management. However, losses of NH_3 from N-fertilisers applied to grass grazed by livestock, are difficult to distinguish from subsequent NH_3 emissions from urine patches produced by grazing animals (Black et al. 1984). In consequence NH_3 losses from grazed grassland, (but not following manure spreading), are dealt with in this chapter. Persistent Organic Pollutants are dealt with separately under SNAP code 100600, Use of Pesticides.

Emissions of N gases from fertilised agricultural land are generally related closely to the amount and, in some cases, type of fertiliser -N applied.

This chapter is a development of chapter ag100100 (EEA 1996) which considered only emissions of NH_3.

Sub-code 100106, Fallows, is not included, as N-fertiliser will not be applied to such land. In most cases there is insufficient evidence to discriminate between the sub-codes when estimating emissions. However there is some evidence that NH_3 emissions from grassland

and rice fields are significantly different to NH_3 emissions from the other sub-codes. Separate NH_3 emission factors are therefore used for 100103 and 100105.

2 CONTRIBUTIONS TO TOTAL EMISSIONS

Fertilised agricultural land typically contributes approximately one tenth of the total source strength for European emissions of NH_3, N_2O and NO.

The major source of NH_3 in Europe is volatilisation from livestock excreta. While 10-20% of agricultural NH_3 emissions have been estimated to derive from the volatilisation of N-fertilisers and from fertilised crops (Asman 1992; ECETOC 1994). This range may be compared with the estimate of the CORINAIR94 inventory (ETCAE, 1997) shown in Table 2.1. CORINAIR estimated a contribution of *c.* 5% to the total which is probably an underestimate compared with more recent values.

The CORINAIR inventory estimated that, via soil processes, fertilisers and crops contributed *c.* 20% of N_2O emissions on a European scale. Soils and crops are considered to be a net sink for most NO_x compounds. However NO may be released from soils during nitrification following mineralisation of N from incorporated crop residues and soil organic matter. Only NO emissions are therefore discussed. No figures were provided by CORINAIR for NO emissions. Estimates of NO emissions are very uncertain, but soils may contribute c. 8% of total European emissions. On a hot summer day this fraction may increase to *c.* 27% (Stohl *et al.* 1996).

Table 2.1: % Contribution of total emissions of the CORINAIR94 inventory
(28 countries)

Source-activity	**SNAP-code**								
		SO_2	NO_x	NMVOC	CH_4	CO	CO_2	N_2O	NH_3
Cultures with Fertilisers	100100	-	3.0	0.4	4.3	-	-	23.1	5.3

0 = emissions are reported, but the exact value is below the rounding limit (0.1 per cent)
- = no emissions are reported

As can be seen from Table 2.1, VOCs from this SNAP Code represent < 1% of current total emission estimates, and do not therefore require a methodology for calculation. However given current uncertainties over the magnitude of VOC emissions from agricultural crops, some information is given in this chapter, in order to provide background information, and to highlight current uncertainties.

3 GENERAL

3.1 Description

3.1.1 Ammonia

The best information on NH_3 emissions from cultures with fertilisers concerns the direct emissions following fertiliser-N application. The evidence for direct emissions from, and uptake by, plant foliage is also good, though estimates of net emissions are much more uncertain. Although estimates of the component emissions from crop foliage have been made (ECETOC 1994), it is often difficult to separate the direct fertiliser and plant emissions in practice, since both are a function of fertiliser-N supply, and in many experiments total emissions were measured. General reviews and estimates of NH_3 from these sources have been provided by Asman (1992), ECETOC (1994) and Sutton et al. (1995b).

Emissions of NH_3 from mineral fertilisers depend on the type of N-fertiliser applied, soil type (especially soil pH), meteorological conditions and time of application in relation to crop canopy development. In particular, the type of N-fertiliser applied has a great effect on the magnitude of emissions (Whitehead and Raistrick 1990). Emissions are largest from urea fertiliser because it hydrolyses in the soil and releases NH_3. Emissions from ammonium sulphate (AS) may also be large, but these are very dependent on soil pH, with larger emissions from calcareous soils. Other fertilisers, such as ammonium nitrate (AN), are more neutral in pH and produce much smaller emissions. These are often difficult to distinguish in measurements from plant-atmosphere fluxes. Fertilisers containing only nitrate (NO_3^-) will not emit NH_3 directly, but may increase NH_3 emissions by fertilised crops.

The estimates of NH_3 emission from decomposing crop residues are also extremely uncertain, and emissions from this source are likely to be very variable. The limited experimental work (Whitehead and Lockyer 1989) found only emission from grass foliage with a high N content where much N-fertiliser had been applied, and was restricted to laboratory measurements which may overestimate emission. Recent measurements have also indicated significant NH_3 emissions from decomposing brassica leaves (including oilseed rape, cauliflower), especially after cutting (Sutton et al. 1996; R Harrison, ADAS, UK, pers. comm.).

Depending on the interpretation of results, emissions from growing vegetation and from decomposing grass herbage may be treated as an additional emission. Or they may be included together with soil emissions as a single emission factor. The time scale over which the emission estimates are made is important to note. Fertiliser emissions are largest in the days after application, but in some instances (e.g. urea applied in dry conditions resulting in a slow hydrolysis), fertiliser emission may proceed for over a month after application (Sutton et al. 1995a). For background emissions (other than initial fertiliser losses) during the plant growing period, most of the emission occurs indirectly from the foliage. However, as well as being influenced by air concentration and environmental conditions, both emission and deposition occur on diurnal cycles. It has been suggested that for some arable ecosystems, on an annual basis, foliar emission may balance dry deposition to the same vegetation (Sutton et al. 1995a). Foliar emissions are expected to be larger from annual cereal crops than from fertilised agricultural grassland, since much of the emission may occur during the grain ripening and vegetation senescence phase (Schjørring 1991). In contrast, where agricultural grassland, or other crops, are cut and left in the field for extended periods, decomposition may result in emissions of similar magnitude. Emissions from this source are extremely uncertain, and probably vary greatly from year to year depending on environmental conditions and success of harvests.

Emissions of NH_3 from grazed grassland have been shown to increase with increasing fertiliser-N application (Jarvis et al. 1989; Bussink 1992). Moreover the proportion of NH_3 emitted increases with increasing fertiliser-N.

Particularly large emissions (*c.* 30% of N applied), have been measured following application of urea and AS to flooded rice fields.

3.1.2 Nitrous Oxide

In soil N_2O is produced predominantly by two microbial processes: nitrification (the oxidation of ammonium (NH_4^+) to nitrate (NO_3^-) and denitrification (the reduction of NO_3^- to gaseous forms of N, ultimately N_2O and N_2). The rate of N_2O production is primarily dependent on the availability of mineral N in the soil (e.g. Bouwman 1996) Maximum N_2O emissions are generally observed within 2 to 3 weeks of N-fertiliser application. The magnitude of the emissions depend on the rate and form of fertiliser applied, the crop type and the soil temperature and soil moisture content. However, it is not possible to derive emission factors for different fertilisers or soil types from existing data (Bouwman 1996). Therefore, the IPCC method defines only one emission factor for all types of N input.

Following the IPCC Methodology (IPCC/OECD 1997), N_2O emissions from agricultural soils may be calculated as the sum of :

i. direct soil emissions (1.25% of N inputs are emitted as N_2O-N); (where N inputs are from fertilisers, biological N fixation and crop residues). See IPCC Worksheet 4-5, sheet 1.

ii direct N_2O emissions from cultivation of histosols (IPCC Worksheet 4-5, sheet 2).

iii. direct soil emissions (2% of N inputs) from grazing animals (IPCC Worksheet 4-5, sheet 3).

iv. indirect emissions following deposition of NH_3 and NO_x (1% of N deposited as NH_3 and NO_x is subsequently re-emitted as N_2O), or leaching or run off (2.5 % of N leached or run off, IPCC Worksheet 4-5, sheets 4 and 5).

Prior to estimation of direct N_2O emissions, fertiliser N inputs are reduced by 10%, and excretal N returns by 20%, to allow for N lost as NH_3. Emissions from animal waste management and manure spreading are included in SNAP Code 100500, Manure Management.

Direct emissions from cultures with fertilisers include emissions which are induced by N input (fertiliser, excretal N deposited during grazing, biological N fixation and crop residues). In addition, cultivation of organic soils (histosols) is regarded as a direct source of N_2O. The magnitude of direct N_2O emissions varies with a range of soil and environmental factors. Application of N-fertiliser to, or incorporation of N-rich crop residues into, moisture-retentive soils produces greater N_2O emissions than application to free-draining soils (Skiba et al. 1992). Application to or incorporation into warm soils is also likely to lead to greater emissions than from soils which are cold. However, recent studies showed, that the largest N_2O emissions occur during thawing of frozen soils (Müller et al. 1997), and the total emissions between November and February were 50% of the total annual flux (Kaiser et al. 1997). Rapid crop growth, and demand for NO_3^--N, will reduce N_2O emissions by reducing the pool of mineral N available for denitrification (Yamulki et al. 1995). Increased exudation of C from plants may also increase denitrification.

These soil and environmental factors also influence the magnitude of indirect N_2O emissions following atmospheric deposition of NH_3 and NO_x.

3.1.3 Nitric Oxide

Nitric oxide (NO) may be emitted either as a consequence of nitrification, or denitrification. In cultures with fertilisers, where pH is likely to be maintained above 5.0, nitrification is considered to be the dominant pathway of NO emission (Remde & Conrad 1991; Skiba et al. 1997). The main determinant of NO production in agricultural soils is mineral N concentration (Skiba et al. 1997). This is increased by N-fertiliser application, excretal N deposited during grazing, crop residue incorporation and cultivation.

Current data on NO emissions in relation to fertiliser-N use were reviewed by Skiba et al. (1997). Losses ranged from 0.003 to 11% of applied fertiliser-N, with a geometric mean emission of 0.3% applied N. In view of the sparse and skewed nature of the data, this estimate is proposed in preference to that of Yienger & Levy (1995) who used an arithmetic mean of 2.5% loss of fertiliser-N to estimate NO emissions.

Activities such as tillage and incorporation were considered to increase NO emissions by a factor of 4 (Skiba et al. 1997). Thus a knowledge of the N concentration and mineralisation rate of crop residues could provide an estimate of soil NH_4^+ on which to base an emission estimate. A knowledge of soil N content could also allow an estimate to be made of NO emissions following cultivation.

3.1.4 Volatile Organic Compounds

Volatile Organic Compounds (VOCs) are defined as “all those organic compounds, other than methane, which can produce photochemical oxidants by reaction with nitrogen oxides in the presence of sunlight”.(ref to be added)

Three categories of sources may be distinguished:

1. activities that emit VOCs by combustion or evaporation;
2. land clearing, including burning;
3. Biogenic processes.

The primary sources in the agricultural sector are:

1. burning stubble and other plant wastes;
2. The use of organic solvents in pesticide production;
3. Anaerobic degradation of livestock feed and animal excreta.

These 3 major sources are dealt with elsewhere. Stubble burning in SNAP code 100300, emissions from burning other crop residues in SNAP code 090700 (Open Burning of

Agricultural Wastes). Emissions from livestock manures are included in SNAP Code 100500, Manure Management.

The emission of some VOCs may be of benefit to plants, e.g. to attract pollinating insects, while others may be waste products or a means of losing surplus energy (Hewitt and Street 1992). Ethene emission has been observed to increase when plants are under stress. Factors that can influence the emission of VOCs include temperature and light intensity, plant growth stage, water stress, air pollution and senescence (Hewitt and Street 1992). Emissions of VOCs from plants have usually been associated with woodlands, which predominantly emit isoprenes and terpenes (König et al. 1996). Hewitt and Street (1992) took qualitative measurements of the major grass and crop species in the UK (except for barley, *Hordeum vulgare*). The only crop species producing any significant emissions was Blackcurrant (*Ribes nigrum*). However these workers cautioned against classifying plants as ‘non-emitters’ on the basis of limited measurements, as plant growth stage had been shown to be an important factor in emission. The role of the soil as a source or sink of VOCs requires investigation

Hewitt and Street (1992) concluded that trees are the main emitters of non-methane hydrocarbons (NMHCs). Other plants, and crops are negligible in comparison. König et al. (1996) noted that in earlier studies NMHCs had been regarded as the major component of VOC emissions. However König et al. (1996) found oxygenated VOCs to be the major VOC emissions from cereals. In that study emissions were not invariably greater from trees than from agricultural crops. Total emissions of NMHCs per unit of dry matter ($\mu g\ g^{-1}\ ha^{-1}$) were : wheat, 0.01; beech (*Fagus sylvatica*), 0.08-0.20; hornbeam (*Carpinus betulis*), 0.16; rye,0.22-0.27; oilseed rape, 0.20-0.32; birch (*Betula pendula*), 0.56; and oak (*Quercus petrae*), 0.78. Emissions were increased during flowering for rape, but not for rye.

3.2 Definitions

Animal Manures. Animal excreta deposited in houses and on yards, collected, either with bedding or without, to be applied to land.

Livestock excreta. Livestock excreta deposited at any time, including while grazing.

Fertilised agricultural grassland. Grassland, to be used for either cutting grass or conservation, grazing or both, to which synthetic N-fertilisers have been applied.

Crop residues. The unharvested parts of crops that are left on the field and ultimately incorporated into the soil.

3.3 Controls

3.3.1 Ammonia

Emissions of NH_3 from crops have not generally been seen as a major option for control, primarily because the emissions from animal husbandry are much larger and therefore provide greater scope for reducing total emissions.

However, there may be potential for reducing crop emissions by switching from urea to other N-fertilisers. Urea has been considered to contribute approximately 50% of the fertiliser emissions in western Europe (ECETOC 1994) because of its greater NH_3 volatilisation rate. A potentially effective control of fertiliser emissions would, therefore, be to use alternative N-fertilisers with smaller NH_3 emissions. A further possibility is to add urease regulators/inhibitors to urea fertiliser which are expected to reduce emissions. Costs of these measures would include the differential price of more expensive fertilisers or of inhibitors. However, it should also be noted that urease inhibitors may have other undesirable environmental effects which need to be assessed before these are recommended. The most effective inhibitors have been toxic heavy metals (eg Hg and Cu), and phenolic compounds which may have a general toxicity to micro-organisms (Fenn and Hossner 1985).

As NH_3 emissions are strongly a function of N supply, another potential control is to use cultivars or crop species which require less N. Use of less N-demanding species and cultivars will generally reduce total produce yields, the costing of which may be difficult because of the close link to produce supply and market values. However, it may be appropriate to consider reduction in fertiliser-N inputs where these have an additional benefit for other environmental effects, such as reducing NO_3^- leaching.

Emissions may also be reduced by placing the fertiliser granule into the soil at the same depth as the seed (*c.* 7-8 cm). This will only be applicable for crops sown in the spring (apart from grass reseeds in autumn). When urea is used care needs to be taken to ensure the fertiliser is not placed so close to the seed that germination is inhibited. The NH_3 emissions from placement of fertilisers have been estimated to be negligible (assuming that N supply is dimensioned correctly). Deep placement of fertiliser granules is a common technology and has been used for many years in Finland (Aura 1967).

Incorporation of fertiliser-N prior to rice planting, or delaying application until panicle initiation, have been shown to reduce NH_3 emissions from rice fields (Humphreys et al. 1988). These are already standard practices in the USA (Bacon et al. 1988). Freney et al. (1988) warned that measures to reduce NH_3 emissions from rice cultivation may not reduce total N losses in soils with large nitrification or denitrification rates.

Reducing fertiliser-N applications to grassland may be effective in reducing NH_3 emissions per unit area. However this will reduce milk yield and liveweight gain, unless extra forage is made available. The provision of such extra forages may increase NH_3 losses, either at grazing or in buildings, by increasing excretal returns.

It should be noted that few of these changes have so far been applied by countries as measures to limit NH_3 emissions, and further work would be required to provide a detailed evaluation of all these possibilities.

3.3.2 Nitrous Oxide

Since emission of N_2O is a consequence of nitrification as well as denitrification (e.g. Klemendtsson et al.1988; Arcara et al. 1990), the greatest potential for reducing N_2O emissions will come from reducing mineral N (NH_4^+ and NO_3^-) concentrations in soils. This may be done most simply by reducing inputs of fertiliser-N. As stated in section 3.2.1, such a measure will have a significant cost if it reduces crop yields. However some scope may remain for better matching of N-fertiliser to crop requirement. This may be done by avoiding N applications in excess of the economic optimum. Such applications are sometimes made as an insurance against under-fertilising. To reduce the likelihood of excessive N fertilisation care should be taken, when deciding N-fertiliser applications, to make full allowance for N available in the soil from previous crop residues, organic manure applications and mineralisation of soil organic matter. Careful timing of fertiliser-N application may also reduce N_2O emissions. Crops and soil microbes may be regarded as being in direct competition for the mineral N in soil (Recous et al. 1988). If large amounts of N-fertiliser are applied to the soil at times when plant growth is limited, and when soil moisture and temperature are favourable, denitrifying and nitrifying bacteria may use the mineral N as a substrate. However if the N-fertiliser is applied to an actively-growing crop, much of it may be taken up quickly by the crop, and removed from sites of bacterial activity. Timing of fertiliser-N application to coincide with crop demand is already recommended in many countries to reduce NO_3^- leaching. Preliminary results from a UK study (S Ellis pers. comm.) suggest this strategy may also be effective in reducing N_2O emissions.

The effect of fertiliser type on the emission of N_2O is inconclusive, and is therefore not included in the IPCC methodology. However, some studies suggest, that fertiliser - induced emissions of N_2O may be greater with the use of anhydrous ammonia and organic N fertilisers (Bouwman, 1996).

Timing the incorporation of crop residues, to avoid incorporating when soils are poorly aerated, may also give some reduction in N_2O emissions (Flessa and Beese 1995). The relative importance of nitrification and denitrification need to be defined, if correct soil management is to be applied. Mitigation options to reduce N_2O emissions from agricultural soils are further discussed by Mosier et al. (1996).

3.3.3 Nitric Oxide

Since, in temperate climates, NO emissions are considered to be predominantly a consequence of nitrification, the use of urea fertiliser may produce larger NO emissions than equivalent amounts of N applied as AN. While at present there is insufficient data to discriminate between fertiliser-N sources (Skiba et al. 1997), the substitution of AN for urea to reduce NH_3 emissions, may also give some reduction in NO emissions.

Currently the only other possible option is to ensure that applications of N-fertiliser are no greater than is needed for optimum crop yield, by making full allowance for the N supplied by crop residues, organic manures, previous N-fertiliser applications, and mineralisation of soil N. Fertiliser application should also be timed to match crop demand.

3.3.4 Volatile Organic Compounds

No potential controls have been proposed for VOC emissions from fertilised crops.

4 SIMPLER METHODOLOGY

4.1 Ammonia

Noting the interdependence of direct fertiliser emissions and subsequent emissions from foliage and decomposing material of fertilised vegetation, the emissions are treated here as a single integrated term. These are estimated as % losses of the fertiliser-N use for each of the main fertiliser categories. In the simple methodology the % N emissions factors are taken to be the same for all countries. Soil type and climate are expected to affect emissions and an approach is given in the detailed methodology (section 5) to account for this.
The emission factors for the simple methodology are provided in Table 4.1. These are based largely on the estimates of Asman (1992), ECETOC (1994) and Sutton et al. (1995b). The combined fertiliser-plant emission factors are smaller than the totals of ECETOC (1994), since in the original estimates of ECETOC their emissions factors referred to just fertiliser losses, while they provided an additional emission from indirect foliar emissions (not shown in Table 4.1). In contrast the estimates here are larger than the estimates of Sutton et al. (1995b).

It should be noted that the estimates published by Buijsman et al. (1987) are now considered to be out of date and overestimate NH_3 emissions.

To calculate NH_3 emissions from fertilised cultures in a country, the use of each fertiliser type (expressed as mass of fertiliser-N used per year), is multiplied by the appropriate emission factor, and the emissions for the different fertiliser types summed. A simple spreadsheet for this calculation is provided in the detailed methodology (see section 5). Emissions of NH_3-N from fertilisers applied to grass cut for hay or silage may be calculated using the same factors as for arable and other crops. Separate emission factors are used for NH_3 emission from grazed grassland.

Table 4.1: Simpler methodology estimates of total NH_3 emissions from cultures due to fertiliser volatilisation, foliar emissions and decomposing vegetation (second column). The estimates are compared with other literature values. Values are kg NH_3-N volatilized per kg of N in fertilisers applied (100* NH_3-N/fertiliser N).

Fertiliser type	**Present simpler methodology to apply**	**Asman (1992) (Europe)**	**ECETOC (1994) Group II European countries)**	**Sutton et al. (1995) (UK)**
Estimates from	fertiliser and plants	fertiliser	fertiliser	fertiliser and plants
Ammonium sulphate	.08	.08	.10	-
Ammonium nitrate	.02	.02	.02	.01
Calcium ammonium nitrate	.02	.02	.02	.01
Anhydrous ammonia	.04	.01	.04	-
Urea	.15	.15	.15	.10
Combined ammonium phosphates (generally di-ammonium phosphate)		.04	.05	-
Mono-ammonium phosphate	.02			
Di-ammonium phosphate	.05			
Other complex NK, NPK fert	.02	.02.5-.04	.02	.025
Nitrogen solution (mixed urea and ammonium nitrate)	.08	-	.08	-

To estimate NH_3 emissions from grazed grassland, Jarvis and Bussink (1990) proposed a function of the form

$$V = a\, b^{N} . \tag{1}$$

where $V = NH_3$-N emission
N = fertiliser-N application (kg ha^{-1})

This function was subsequently updated and used to calculate grazing emissions for the UK (Pain et al. 1997),where:

$$V = -2.27 + 0.0683N \tag{2}$$

To estimate NH_3 emissions from grazed grassland, b will be equal to the average annual fertiliser-N application to grazed grass. This approach estimates both emissions from fertiliser-N, and subsequent emissions from excreta deposited during grazing. In the studies from which these data were derived, AN or calcium ammonium nitrate were the sources of fertiliser-N

Thus the above equation may underestimate losses from grassland when urea is applied. No distinction is made between emissions from cattle and sheep. However in general less fertiliser-N is applied to grass grazed by sheep, usually <100 kg ha^{-1} yr^{1}, and so in practice emissions from sheep grazing are not likely to be greatly overestimated.

Equation (2) was derived almost entirely from measurements of NH_3 emissions in N-W Europe. The relationship may not give accurate estimates of emissions from grazing in drier, or warmer climates.

4.2 Nitrous Oxide

The methodology used here follows the approach taken by IPCC/OECD (1997) in order to maintain consistency between the different emission inventories. Emissions arising from manure application are dealt with in SNAP Code 100500, Manure Management. The IPCC detailed methodology requires the following input data:

1. Total synthetic fertiliser-N applied

2. Total N content of fertilised crop residues, biological N_2 fixation and excreta from grazing animals returned to the soil.

3. Area of organic soils (histosols) cultivated in the country.

4. Estimate of atmospheric emission of NH_3 and NO_x.

5. Estimate of N lost from soils by leaching and runoff.

These input data can be estimated from FAO data (see IPCC/OECD 1997), see Table 4.2.

Table 4.2: Summary of IPCC source categories (IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2: Workbook, 1997) to be reported as CORINAIR sub-sectors for agriculture.

CORINAIR SUB-SECTOR (snap code)	**IPCC N_2O SOURCE (IPCC WORKBOOK WORKSHEET**
Cultures with/without fertilisers (100100.100200)	- Direct soil emission due to N-inputs excluding manure (4-5, sheet 1, excluding animal waste Faw) - Direct soil emissions due to histosol cultivation (4-5, sheet 2) - Direct soil emissions from grazing animals; pasture, range & paddock (4-5, sheet 3) - Indirect emissions due NH_3 and NO_x emissions from synthetic fertiliser use and grazing animals (4-5, sheet 4, excluding animal waste used as fertiliser) - Indirect emissions due N leaching/runoff from synthetic fertiliser use and grazing animals (4-5, sheet 5, excluding animal waste used as fertiliser
Manure Management (100500)	- Manure management: 6 waste management systems (4-1, sheet 2, excluding pastue, range & paddock) - Direct soil emissions due to manure N-inputs excluding grazing animals (4-5, sheet 1, row for animal waste Faw only) - Indirect emissions due NH_3 and NO_x emissions from animal waste excluding grazing animals (4-5, sheet 4, animal waste used as fertiliser only) - Indirect emissions due N leaching/runoff from animal waste excluding grazing animals (4-5, sheet 5, animal waste used as fertiliser only)

The default emission factors for the above are given in Table 4.3. More detail may be obtained from IPCC Worksheet 4-5, sheets 1-5.

The N_2O emission may be calculated as :

$F\mathit{N_2O\text{-}N}$ = 0.0125 * ‘net’ N inputs 0.02* ‘net’ N inputs from grazing + 0.01 * (NH_3 + NOx-N emissions to atmosphere + 0.025 * N (leached and/or run off) (3)
where units are generally expressed as kg N ha^{-1} yr^{-1}.

In the case of organic soils (histosols) an additional emission of 5 kg N ha^{-1} yr^{-1} is added (Table 4.3).

The IPCC guidelines estimate direct soil emissions as a fraction of N inputs to soils, excluding NH_3 emissions. This ‘net’ N input is calculated for N-fertilisers as :

‘net’ N input (kg N ha^{-1}) = fertiliser-N input (kg N ha^{-1}) * 0.9 (4)

To calculate the subsequent N_2O emission, this ‘net’ N input is multiplied by the emission factor 0.0125 kg N_2O-N per kg ‘net’ N input.

$F\mathit{N_2O}$ (fertiliser) = ‘net’ fertiliser-N input (kg N ha^{-1}) * 0.0125 N_2O-N kg N input^{-1} (5)

For excretal N deposited during grazing, the ‘net’ N input is calculated as :

‘net’ input (kg N ha^{-1}) = Excretal-N input (kg N ha^{-1}) * 0.8 (6)

An estimate of excretal-N deposited during grazing is given for each major livestock class in SNAP Code 100500, Manure Management.

To calculate N_2O emissions from N deposited during grazing, the ‘net’ N input is multiplied by the emission factor 0.02 kg N_2O-N per kg ‘net’ grazing N input

$F\mathit{N_2O}$ (grazing) = ‘net’ grazing N input (kg N ha^{-1}) * 0.02 kg N_2O-N kg N input^{-1} .. (7)

Table 4.3: Default emission factors for N_2O emissions from cultures with fertiliser (IPCC/OECD, 1995)

Source of N_2O	**Emissions Factor**
Direct soil emissions	
N inputs (fertiliser,biological N fixation and crop residues)[#]	0.0125 kg N_2O-N/kg ‘net’ N input^{-1}
cultivation of histosols	5 kg N_2O-N ha^{-1} yr^{-1}
Excretal N deposited during grazing†	0.02 kg N_2O-N kg ‘net’ N input^{-1}
Indirect emissions	
Emission of NH_3 and NO_x	0.010 kg N_2O-Nkg NH_3-N and NO_x-N emitted^{-1}
N leaching and runoff	0.025 kg N_2O/kg N leached or lost by run off^{-1}

[#] Manure N inputs are dealt with in SNAP Code 100500, Manure Management

The IPCC estimates were developed for wide area estimates to be integrated up to the global scale. As such a number of simplifications had to be made to suit the availability of data. A key approximation on this scale is that atmospheric N deposition equated to atmospheric emissions of NH_3 and NO_x. On a European scale, and particularly within the Convention on Long Range Transboundary Air Pollution, this might be considered an unacceptable simplification, given the different locations of source and sink areas. In this case atmospheric N deposition estimates should be taken from national estimates or EMEP (e.g. Barrett & Berge 1996).

It should be recognised that although N_2O emissions as a function of atmospheric N inputs will be significant, for fertilised agricultural land these will generally be small compared with emissions resulting from fertiliser-N inputs. This term should nevertheless be included to maintain consistency across different land-uses.

4.3 Nitric Oxide

A simple methodology similar to that described by the IPCC for N_2O flux estimates is applied for estimating NO emissions, i.e. emissions that arise directly as a result of N-fertiliser application. To estimate NO emissions, the total usage of mineral N-fertiliser in the country is required. Emissions of NO-N are calculated as 0.3% of total fertiliser-N applied (Skiba et al. 1997). This 0.3% value was derived from a much smaller data set compared to the equivalent value used for the N_2O fertiliser induced emission calculation. The certainty in the 0.3% value can therefore be greatly increased by further rigorous intensive measurements.

4.4 VOCs

An approach for estimating the emissions from grassland and crop is given in Chapter 110400, Natural Grassland. The same approach may be adopted here. It is important to use the same land use data as for other emitted species, and to avoid double counting. If the method given in Chapter 110400 is used, emissions from fertilised agricultural land must be reported under Chapter 100100.

5 DETAILED METHODOLOGY

5.1 Ammonia

5.1.1 Emissions from crops and cut grassland

To provide a more detailed methodology it is desirable to distinguish between the different climates and soil types for different countries. The justification for this is well established, as crop emissions are known to be larger in warmer climates (Fenn and Hossner 1985), while soil emissions (direct fertiliser losses) generally increase at higher soil pH (e.g. Whitehead and Raistrick 1990). Given the need to generalize, only a broad scale approach is possible to apply these known differences in inventories. A first attempt has been applied by ECETOC (1994), and is used as the basis for the present classification. Countries are categorized into 3 types:

Group I	Warm temperate countries with a large proportion of calcareous soils (e.g. Greece, Spain).
Group II	Temperate and warm-temperate countries with some calcareous soils (or managed with soil pH >7), but with large areas of acidic soils (e.g. Italy, France, UK, Eire, Portugal, Belgium, Netherlands, Luxembourg.
Group III	Temperate and cool-temperate countries with largely acidic soils (e.g. Nordic countries, Germany, Switzerland, Austria).

The countries listed in brackets are as assigned by ECETOC (1994), which restricted its coverage to western Europe. Other UNECE countries may be added to this classification. Here the main extension would be that countries with subtropical and continental climates (eg Eastern Mediterranean, Southern Steppe) would be expected to fall into Group I.

In respect of urea, a greater NH_3 loss on calcareous soils may not be justified. While NH_3 losses from AS and AN have been found to increase markedly with increasing pH (e.g. Whitehead and Raistrick 1990), NH_3 loss from urea is less dependent on initial soil pH, since hydrolysis of urea will increase pH immediately around the fertiliser granule to *c.* 9.2 (Fenn 1988). Moreover reaction with calcium ions reduces the volatilisation potential of $(NH_4)_2CO_3$ produced by urea hydrolysis (Fenn and Hossner 1985). In contrast to other N-fertilisers, NH_3 loss from urea did not increase consistently with pH, and was not greater on a calcareous soil (Whitehead and Raistrick 1990). This was considered due to differences in cation exchange capacity (CEC). Whitehead and Raistrick (1993) also found losses of NH_3 from cattle urine were no greater on calcareous than on non-calcareous soils. The best correlation with NH_3 loss was with CEC. Gezgin and Bayrakli (1995) measured NH_3 losses from urea, AS and AN on calcareous soils in Turkey. Losses from AS (*c*. 16%) and AN (*c.* 5%) were greater than those measured on non-calcareous soils by Somner and Jensen (1994), which were <5% and <2% respectively. However losses from urea at *c*. 8% were less than those measured by Sommer and Jensen (1994). Nevertheless a greater emission factor for urea in Group 1 countries is justified by the greater temperatures. The large proportion of calcareous soils will however increase NH_3 losses from AS (Fleisher et al. 1987).

Values of emission estimates for the more detailed methodology are provided in Table 5.1. A simple spreadsheet is provided for calculating culture NH_3 emissions in Table 9.1.

5.1.2 Emissions from grazed grassland

Van der Weerden and Jarvis (1997) reviewed data from field measurements of NH_3 loss following application of N fertilisers to grassland and arable land. They concluded that NH_3 losses from urea are greater by a factor of 2 on grassland. This greater potential for NH_3 loss had been attributed to greater urease activity in grassland soils by O'Toole and Morgan (1985). This will give the following NH_3 losses (kg NH_3-N kg fertiliser -N^{-1} applied) for urea:

Arable land	0.16 (Zone I), 0.12 (Zones II and III);
Grassland	0.30 (Zone I), 0.25 (Zones II and III).

These coefficients are for estimating emissions only from grass that is cut. The method for calculating NH_3 emissions from grazed grassland is given in Section 4.1

Table 5.1: Detailed methodology estimates of total NH_3 emissions from cultures due to N fertiliser volatilisation, foliar emissions and decomposing vegetation. Values are kg NH_3-N volatilised per kg fertiliser-N applied (100 * NH_3-N/fertiliser-N^{-1})

Fertiliser type	Group I	Group II	Group III
Ammonium sulphate	.15	.10	.05
Ammonium nitrate	.03	.02	.01
Calcium ammonium nitrate	.03	.02	.01
Anhydrous ammonia	.04	.04	.04
Urea	.20	.15	.15
Combined ammonium phosphates (generally di-ammonium phosphate)	.05	.05	.05
Other complex NK, NPK fertilisers	.03	.02	.01
Nitrogen solutions (mixed urea and ammonium nitrate)	.08	.08	.08

5.1.3 Emissions from Rice Fields

Losses of NH_3 following applications of N-fertiliser to flooded rice soils are considered to be potentially greater than from other cropping systems (Fenn and Hossner 1985). Vlek and Crasswell (1979) measured NH_3 losses of up to 50% of urea-N applied, and up to 60% of AS-N. More recent studies of NH_3 emissions following urea application to flooded soils, have measured losses in the range *c*. 8-56% of urea-N, with a median loss of 30%. Many of these studies used micrometeorological techniques. Patel et al. (1989), in a review, concluded that earlier studies using chambers, had overestimated NH_3 losses in the field.

A loss coefficient of 0.30 NH_3-kg N kg Urea-N applied^{-1} should therefore be used to calculate NH_3 emissions from flooded rice fields.

As noted above, application of fertiliser-N to flooded rice fields is not standard practice in all countries. When application is either to the soil before flooding, or when the crop is at panicle initiation, losses will be significantly less. In such cases, emissions should be calculated using the coefficients given in Table 4.2.

No data was found on NH_3 losses following AN application to rice fields. In the absence of more specific data, emissions should be calculated from Table 4.2. Fillerey and De Datta (1987), found NH_3-N losses of 37% from AS applied to flooded rice fields. We propose using the same loss coefficients for AS as for urea, when estimating NH_3 losses from rice field.

5.2 Nitrous Oxide

No more detailed methodology is proposed for estimating emissions of N_2O. However countries may use their own estimates for any step in the IPCC method if this will increase precision. In particular countries are encouraged to estimate NH_3 losses using the methods described in this chapter, rather than the IPCC default values.

5.3 Nitric Oxide

A more detailed methodology, based on the soil temperature and the land use type has been developed by Williams et al. (1992).

$$F_{NO} = A * \exp(0.071 * T_s) \quad (8)$$

where
F_{NO} = NO flux, (ng $Nm^{-2}\ s^{-1}$)
Ts = Soil temperature, (degrees Celsius)
A = Experimentally derived constant for the land use types of grasslands and pasture, forests and urban trees, and the individual agricultural categories

To improve this approach, N input and soil moisture contents (Meixner, 1994) need to be included in the equation. However at this stage, there is no sufficiently robust analysis to use as a basis for a more detailed methodology. This methodology produces much greater estimates of NO emission than are given by the simple methodology, and the authors conclude it is not appropriate to use at this stage. Details of this method are given in chapter 110300.

5.4 VOCs

See section 4.4.

6 RELEVANT ACTIVITY STATISTICS

Information is required on the annual consumption of major N- fertiliser types by each country. This may be obtained from IFA (1992) as well as from national agricultural censuses. Information may also be required on the amounts and N concentrations of crop residues returned to the soil. This may be obtained from statistics on crop production. The amounts of N deposited by animals while grazing are given in SNAP Code 100500, Manure Management. The area of organic soils (histosols) under cultivation is also useful. Finally information is needed on emissions of NH_3 and NO_x.

Where spatially disaggregated inventories of fertilised culture emissions are required (section 12), information on the spatial distribution of different crop types and average N-fertiliser inputs to each crop type may be used. In the absence of data on the use of different fertilisers for crop types, the average N-fertiliser inputs to crops may be combined with the average NH_3 emission factor for a country estimated according to Tables 9.1, 9.2 and 9.3 as: Total $NH_3/N_2O/NO$ emission/total N-fertiliser consumption. All the activity statistics required are summarised in Table 9.4.

7 POINT SOURCE CRITERIA

Ammonia, N_2O, NO and VOC emissions from cultures with fertilisers should be treated as area sources.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

The emission factors for NH_3, N_2O and NO losses from cultures with fertilisers are treated as kg of N per kg N applied as fertiliser or, in the case of crop residues incorporated into the soil, and excretal-N deposited during grazing, of the N returned in these forms. Full details of calculations are provided in sections 5 and 6.

9 SPECIES PROFILES

9.1 VOCs

As with forest NMVOC emissions, biogenic emissions from grasslands consist of a wide variety of species, including isoprene, monoterpenes, (alpha-pinene, limonene, etc.), and ‘other’ VOC. The ‘other’ VOC (OVOC) species consist of a large number of oxygenated compounds (alcohols, aldehydes, etc.), and have proven difficult to quantify in atmospheric samples. Progress in quantification of OVOC from European vegetation has been made recently (König et al. 1996) although many more measurement data will be required before reliable attempts to inventory specific OVOC can be made.

Table 9.1: Spreadsheet for calculating NH_3 emissions from cultures with fertilisers according to either the simpler or more detailed methodologies

Group of country (for detailed methodology)			
Column	A	B	C
Fertiliser type	N emissions (from Table 1 or 2) kg NH_3-N kg N applied yr^{-1}	Fertiliser use kg N yr^{-1} (see section 6)	Ammonia emissions kg NH_3 yr^{-1} (A*B*17/14)
Ammonium sulphate			
Ammonium nitrate			
Calcium ammonium nitrate			
Anhydrous ammonia			
Urea			
Mono-ammonium phosphate			
Di-ammonium phosphate			
Other complex NK, NPK fertilisers			
Nitrogen solution (mixed urea and ammonium nitrate)			
Legumes (see section 5)			
Total ammonia emissions in kg NH_3 per year			

Table 9.2: Spreadsheet for calculating nitrous oxide emissions from cultures with fertilisers according to either the simpler or more detailed methodologies

	A	B	
N input	N emission kg N_2O-N kg ‘net’ N applied^{-1}	N input, kg N yr^{-1}	N_2O emission kg N_2O yr^{-1} (A * B * 44/28)
Fertiliser- N	0.0125		
Crop residues N	0.0125		
Excretal- N deposited during grazing	0.020		
Emission of NH_3	0.010		
Emission of NO_x	0.010		
N lost by leaching or runoff	0.025		
	kg ha^{-1}	Area (ha)	
Cultivation of histosols	5		

Table 9.3: Spreadsheet for calculating nitric oxide emissions from cultures with fertilisers according to the simple methodology

	A	B	
N input	N emission kg NO-N kg N applied^{-1}	Fertiliser-N use kg N yr^{-1}	Nitric Oxide emission kg NO-N yr^{-1}
			(A * B * 30/14)
Fertiliser-N	0.003		

This spreadsheet is much less detailed because there are few data on NO emissions from soils.

Table 9.4: Summary of activity statistics which may be required for the simple and detailed methodologies.

Activity Statistic		Source
Synthetic Fertiliser-N use	By type of fertiliser for arable and grassland	IFA (1992)
Amount and N concentration of fertilised crop residues	By crop type	FAO, See IPCC/OECD (1997)
Amount and N concentration of animal excreta deposited during grazing	By Livestock type	SNAP Code 100500, Manure Management
Area of cultivated histosols		FAO, See IPCC/OECD (1997)
Atmospheric emissions of NH_3 and NO_x		ETCAE, (1997)
N lost from soils by leaching and runoff		FAO, See IPCC/OECD, (1997)

10 UNCERTAINTY ESTIMATES

10.1 Ammonia

Although the processes governing the emission of NH_3 from fertilisers and crops are reasonably well understood, the interactions of many biological, chemical and environmental factors make quantitative estimates of emission rather uncertain. The main uncertainty lies in the generalization of emissions factors, rather than the areas of crops under cultivation which is probably accurate in most countries to better than +/- 10%. For example, the ranges of uncertainty for Group II emission factors in Table 4.1 are probably wider than the figures given as emission factors for Groups I and III, which are included in order to avoid bias between countries with different conditions. Overall emissions are probably no better than +/- 50% (a factor of 3).

10.2 Nitrous Oxide

The processes controlling the emission of N_2O from soils are reasonably well understood. Their interactions, and the partitioning between nitrification and denitrification, and hence estimates of emission, have not yet been accurately modelled. Application of fertiliser-N, in most countries, can probably be estimated to within ±10%. However the magnitude of crop residues, and their N contents are only likely to be accurate to within ±25%. Wet deposition of N may be estimated to ± 20%, but dry deposition of NH_3 to no more than ±50% (UKRGIAN 1994). Most importantly fertiliser-N induced N_2O emissions can be estimated with a certainty of a factor of 9 (range 0.25 - 2.25% of N inputs, Bouwman 1996). The importance of winter time N_2O emissions caused by freezing and thawing has only recently been discovered and has not been included in any of the estimates. This will create a further large uncertainty.There will be even greater uncertainty with regard to indirect emissions of N_2O since there are fewer measurements available of N_2O formation from atmospheric deposition, or leached N.

10.3 Nitric Oxide

Much less information is available on factors determining losses of NO from soils. While application of fertiliser-N may be estimated with an accuracy of ±10%, other factors such as returns of N in crop residues and soil N contents may be estimated to within ±25%. However, the greatest uncertainty is over emission factors. Using data from essentially the same body of published work, Yienger and Levy (1995) and Skiba et al. (1997) arrived at mean emission factors almost an order of magnitude different, suggesting an uncertainty of a factor of 10.

10.4 Volatile Organic Compounds

Biogenic VOC emissions for the UK were summarized by Hewitt and Street (1992). These ranged from 38-211 kt yr^{-1} total VOCs. Emissions from woodlands were estimated to be 72% of total biogenic emissions by Anastasi et al. (1991). Thus between *c.* 10 and 59 kt yr^{-1} appear to be of agricultural origin. This compares with the CORINAIR 94 estimate of only 2 kt yr^{-1} for SNAP Code 100100 or <2% of emission from agriculture and forestry. Thus the range of emissions may be uncertain by a factor of 30. However the estimate for agriculture by Anastasi et al. (1991) was recognised as likely to be too large.

Hewitt and Street (1992) concluded that only *c.* 700 plant species, mainly from N. America, had been investigated as isoprene or monoterprene emitters. Few of these were agricultural crops, and quantitative data was available for only a few species. Many measurements had been made at temperatures higher than those prevailing in N and W Europe.

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

11.1 Ammonia

A major criticism of the present estimates is their reliance on simple fixed (%) emission factors, given in relation to amounts of N applied. A first attempt to account for broad scale differences between countries (based on climate and soil type) has been included here (detailed methodology) but it is very much an empirical interpretation of the available data. More work needs to be done in the development of mechanistic process-based models for predicting NH_3 emissions from N-fertilisers and the foliage of fertilised crops, which take into account the known physicochemical equilibria as well as interactions with biological processes to predict net fluxes. It is well established that NH_3 may be exchanged with the soil surface and with leaves via stomata and cuticular absorption/desorption as well as with decomposing leaves, and future work needs to quantify the interactions and exchange cycles between these different components. Studies of NH_3 emissions from grazed grassland have largely been carried out in NW-Europe. Data is needed on emissions in warmer and drier climates.

The current estimates are limited to net emission of NH_3 over the year, and as such integrate both periods of emission from cultures and deposition to them on both diurnal and seasonal scales. Further work is needed in quantifying the temporal variability in emissions as well as the integration of emitting surfaces and depositing surfaces for development of atmospheric models.

11.2 Nitrous Oxide

Current estimates of N_2O emissions are also limited by the use of fixed emission factors. More work needs to be done in the development of process-based models that will allow greater discrimination to be made between soils with different moisture regimes, and between areas of different climate. Emissions of N_2O per kg fertiliser-N applied, have been shown to be greater from grasslands, particularly from grazed grasslands, than from arable crops (Velthof et al. 1996). This is caused by a combination of: soil compaction caused by the grazing animals; localised very high N and C inputs from animal excreta; and in cooler climates grasslands tend to be located on the wetter soils, less suitable for arable crop production. In addition the question of differentiating between fertiliser-N sources needs to be addressed. Emissions from organic N-fertilisers (Bouwman 1996; McTaggart et al. 1997) and anhydrous NH_3 have been shown to be larger than from solid mineral-N fertilisers. Evidence for significantly different emissions according to N source needs to be evaluated.

Estimates of indirect emissions of N_2O are dependent on accurate estimates of NH_3 and N_2O emissions and N leaching and runoff. As long as uncertainties in these estimates are large, then so too will be estimates of indirect N_2O emissions. Losses of N by leaching and run off are not necessarily directly proportional to N inputs, but depend on crop, soil, climate etc. It would be useful therefore to be more specific in this regard.

11.3 Nitric oxide

Reliance on a simple fixed (%) emission factor in relation to the amount of N-fertiliser applied is the major weakness. No account is taken of potentially large differences between climatic regimes. Nor is any account taken of the potential contribution from non-fertiliser sources of N, and from the mineralisation (and hence nitrification) of N already present in soils. There are not enough data available to discuss the effect of grazing on NO emissions, but the localised very high N and C inputs caused by animal excreta are likely to stimulate NO production.

11.4 Volatile Organic Compounds

Lack of measurements of VOC emissions from agricultural vegetation is a considerable weakness. It is unknown whether emissions are related to fertiliser-N inputs.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

12.1 Ammonia

The simplest approach to spatially disaggregate the emissions from cultures with fertilisers is to scale these by the distribution of total arable and fertilised grassland. In a more detailed approach census data on the distribution of different crop types may be combined with characteristic fertiliser inputs to each crop type, together with the overall fertiliser emissions factor estimated from Table 4.2. Where the average N-fertiliser application to crops is derived from similar national data as the fertiliser consumption, there should be a reasonable agreement between the mapped and national total emission. However, caution is required and spatially disaggregated estimates may need to be corrected.

Caution is also required to account for the possible double counting of fertiliser/foliar emissions from grazed grassland, noted in the detailed methodology (section 5). If this effect is to be treated in spatially disaggregating emissions, it may be considered that the emissions from grazed grass, where this is supplied, fertilised with AN or complex fertilisers, are already included in the grazing emissions. In this case, land-use maps of grazed grassland would be required, in a similar way to the distribution to crop types, but here a reduced emission factor applied to account for only emissions from ‘high emissions’ fertilisers. This reduced overall emissions factor may be found by completing a version of Table 4.2 for grazed grassland, not including emissions from AN, calcium AN or other complex fertilisers. Dividing the total NH_3 emission by total N-fertiliser use, multiplied by 17/14, provides an ‘average’ % N volatilised for grazed grassland. This can then be applied with the mapped distribution of grazed grassland. Where only the distribution of total grassland is available, estimates would need to be made of the fraction that is grazed, while account of the temporal overlap of grazing and culture emission should also be taken.

12.2 Nitrous Oxide

Direct emissions may be spatially disaggregated using census data on the distribution of different crops together with mean fertiliser-N inputs to those crops. Data on the distribution of organic soils (histosols) may also be included to improve spatial disaggregation.

Information on climatic variations (temperature and rainfall) within the country should be included. At present no standard model to do this is available. Dividing the country/region into 3 to 4 climatic groups and slightly modifying the IPCC methodology, by increasing and reducing the various emission factors for the individual regions may be a way forward.

Indirect emissions may also be spatially disaggregated if spatial data is available for N deposition and also for N leaching and runoff.

12.3 Nitric Oxide

Emissions due to N-fertiliser application may be spatially disaggregated using census data on the distribution of different crops, together with mean fertiliser-N inputs to those crops, and climatic information as outlined in section 12.2.

12.4 Volatile Organic Compounds

In the absence of specific data for VOC emissions from different agricultural crops, there appears to be little scope at present for spatially disaggregating VOC emissions.

13 TEMPORAL DISAGGREGATION CRITERIA

13.1 Ammonia

As noted in section 11, little information is available to generalize on temporally disaggregating NH_3 emissions from fertilisers and crops. Most of the direct emission from N-fertiliser occurs within a month of application and, for some countries, agricultural statistics may be available on the timing of these applications. Further crop emissions may occur particularly during senescence of crop plants, and may account for *c*. 1-3 kg NH_3- N per ha emission. A major uncertainty with fertiliser, foliar, grazing and decomposing vegetation emissions, is that losses are expected to vary greatly from year to year depending on agricultural and environmental conditions.

13.2 Nitrous Oxide

Most of the direct emission from fertiliser-N occurs with a few weeks of application (Bouwman 1996), and statistics on the timing of fertiliser-N application should be available, for some countries at least. Some data may also be available on the timing of crop residue incorporation. However, until process-based models have been developed and validated it will not be possible to take account of fluxes of N_2O emission that take place when soil mineral N concentrations, soil water regimes and soil temperature combine to produce favourable conditions for denitrification.

Data will be available, for some countries at least on the temporal variation in N deposition and N leaching and runoff.

As for NH_3, losses may vary greatly from year to year, depending upon weather conditions.

13.3 Nitric Oxide

Losses of NO take place mainly as a consequence of nitrification. Peaks in NO emission are therefore likely following application of NH_4^+-based N-fertilisers, incorporation of crop residues and tillage of soils. Data on all these should be available, for some countries at least. At present, however there are insufficient data on NO emissions to quantify these effects. Ultimately, as the mechanisms of NO production become better understood, climatic data may also be utilised to assess when soil and weather conditions are favourable for nitrification, and hence NO production. In common with NH_3 and N_2O, emissions may vary greatly from year to year, depending upon weather conditions.

13.4 Volatile Organic Compounds

Emissions of VOCs are likely to differ according to crop type, crop growth stage, soil type, cultivation and weather conditions. Some temporal disaggregation may be possible, if seasonal variations in emissions by non-agricultural plants, can be assumed to be valid for fertilised crops.

14 ADDITIONAL COMMENTS

Where more detailed methodologies than those described here are used by countries, a detailed description should be given of the methodology used, and comparison made with the results of the methodology described here.

15 SUPPLEMENTARY DOCUMENTS

The main supplementary documentation required for applying the estimates in this chapter are details of national N-fertiliser consumption and areas of fertilised grassland that are grazed. In addition estimates of the amounts and N concentrations of crop residues returned to the soil, together with the area of cultivated organic soils (histosols) will be required. The approximate timing of soil cultivation, including crop residue incorporation will also be useful. Finally information on deposition of NH_3 and NO_x, together with estimates of N leaching and runoff are needed. Where disaggregated estimates are to be made, details on N application rates to crops and spatially disaggregated crop distribution are needed.

16 VERIFICATION PROCEDURES

There are no direct methods to evaluate total inventory estimates of NH_3 emissions from croplands, and verification is dependent on laboratory and micrometeorological field studies of emissions from example situations. In particular, many studies have focused on laboratory measurements and there is a need to provide long-term field measurements using micrometeorological techniques to estimates NH_3 fluxes over a range of crop types in different climates.

Emissions of N_2O, NO and VOCs cannot be verified except by field studies of emissions from example situations. There is a need to obtain long-term field measurements to estimate fluxes over a range of crop types and climates.

17 REFERENCES

Anastasi, C., Hopkinson, L., Simpson, V. J. 1991. Natural Hydrocarbon emissions in the United kingdom. Atmospheric Environment **25A**, 1403-1408.

Arcara, P. G., Gregori, E., Miclaus, N., Cornellini, F. 1990. Denitrificazione e perdite di azoto (N_2O) da suoli coltivati a frumentofertiliszati con urea, nitrato ammonico e letame. Rivista di Agronomia **24 (1),** 19-27.

Asman, W. A. H. 1992 Ammonia emission in Europe: updated emission and emission variations. RIVM report 228471008. RIVM, Bilthoven, Netherlands.

Aura, E. 1967. Effect of the placement of fertiliser on the development of spring wheat. Journal of the Scientific Agricultural Society of Finland **39**, 148-155.

Bacon, P. E., Hoult, E. H., Lewin, L. G., McGarity, J. W. 1988. Ammonia volatilization from drill sown rice bays. Fertiliser Research **16 (3)**,257-272.

Barrett, K., Berge, E. 1996. Transboundary air pollution in Europe. Part 1: Estimated dispersion of acidifying agents and of near surface ozone. EMEP/MSC-W Status report 1996. Norwegian Meteorogological Institute, Blindern, Oslo, Norway.

Bouwman, A. F. 1996. Direct emission of nitrous oxide from agricultural soils. Nutrient Cycling in Agroecosystems **46**, 53-70.

Buijsman, E., Maas, H. F. M., Asman, W. A. H. 1987. Anthropogenic NH_3 emissions in Europe. Atmospheric Environment **21**, 1009-1022.

Bussink, D. W. 1992. Ammonia volatilization from grassland receiving nitrogen fertiliser and rotationally grazed by dairy cattle. Fertiliser Research **33**, 257-265.

ECETOC 1994. Ammonia emissions to air in western Europe. Technical Report 62. European Centre for Ecotoxicology and Toxicology of Chemicals, Avenue E Van Nieuwenhuyse 4, Brussels.

EEA 1996. Atmospheric Emission Inventory guidebook. (Ed G. McInnes). European Environment Agency, Kongens Nytorv 6, Copenhagen.

ETCAE 1997. CORINAIR 94 Summary Report - European Emission Inventory for Air Pollutants. European Environment Agency, Kongens Nytorv 6, Copenhagen.

Fenn, L. B. 1988. Effects of initial soil calcium content on ammonia losses from surface-applied urea and calcium-urea. Fertiliser Research **16**, 207-216.

Fenn, L. B., Hossner, L. R. 1985. Ammonia volatilization from ammonium or ammonium-forming fertilisers. Advances in Soil Science **1**, 123-169.

Fillery, I. R. P., De Datta, S. K. 1986. Ammonia volatilization from ammonia sources applied to rice fields: 1 Methodology, ammonia fluxes and N-15 loss. Soil Science Society of America, Journal **50(1)**, 80-85.

Fleisher, Z., Kenig, A., Ravina, I., Hagin, J. 1987. Model of ammonia Volatilization from calcareous soils. Plant and Soil **103**, 205-212.

Flessa, H., Beese, F. 1995. Effects of sugar beet residues on soil redox potential and N_2O emission. Soil Science Society of America Journal **59**, 1044-1051.

Freney, J. R., Trevitt, A. C. F., Muirhead, W. A., Denmead, O. T., Simpson, J. R.,

Obcemea, W. N. 1988. Effect of water depth on ammonia loss from lowland rice. Fertiliser Research **16 (2)**,97-108.

Gezgin, S., Bayrakli, F. 1995. Ammonia volatilization from ammonium sulphate, ammonium nitrate, and urea surface applied to winter wheat on a calcareous soil. Journal of Plant Nutrition **18 (11)**, 2483-2494.

Hewitt, C. N., Street, R. A. 1992. A qualitative assessment of the emission of non-methane hydrocarbons from the biosphere to the atmosphere in the U.K.: present knowledge and uncertainties. Atmospheric Environment **26A**,3069-3077.

Holtan-Hartwig L., Bøckman O. C., 1994. Ammonia exchange between crops and air. Norwegian Journal of Agricultural Science, Supplement No. 14. 41 pp.

Humphreys, E., Freney, J. R., Muirhead, W. A., Denmead, O. T., Simpson, J. R., Leuning, R., Trevitt, A. C. F., Obcemea, W. N., Wetselaar, R., Cai G-X. 1988. Lloss of ammonia after application of urea at different times todry-seeded irrigated rice. Fertiliser Research **16 (1)**, 47-58.

IPCC/OECD 1997. Revised 1997 IPPC guidelines for national greenhouse gas inventories. OECD, 2 rue André Pascal, Paris.

IFA, 1992. World fertiliser consumption statistics No. 24. 1988/89 to 1989/90. International Fertiliser Industry Association Limited, Paris.

Jarvis, S. C., Bussink, D. W. 1990. Nitrogen losses from grazed swards by ammonia volatilization. Proceedings of the 13th General Meeting of the European Grassland Federation, June 25-29 1990, Banska Bystrica, Czecheslovakia.

Jarvis, S. C., Hatch, D. J., Lockyer, D. R. 1989. Ammonia fluxes from grazed grassland : annual losses from cattle production systems and their relation to nitrogen inputs. Journal of Agricultural Science, Cambridge **113**, 99-108.

Kaiser, E.A., Kohrs, K., Kuecke, M., Schnug, E., Munch, J.C., Heinemeyer, O. 1997. N_2O emissions from different arable crops-importance of N fertilisation levels. In: Proceedings of the 7th International N_2O workshop, Cologne,April 1997.

Klemendtson, L., Svensson, B. H., Rosswall, T. 1988. Relationships between soil moisture content and nitrous oxide production during nitrification and denitrification. Biology and Fertility of Soils **6**, 106-111.

König, G., Brunda, M., Puxbaum, H., Hewitt, C. N., Duckham, S.C., Rudolph, J. 1995. Relative contribution of oxygenated hydrocarbons to the total biogenic VOC emissions of selected mid-European agricultural and natural plant species. Atmospheric Environment **29(8),** 861-874.

McTaggart, I. P., Douglas, J. T., Clayton H., Smith, K. A. (1997) N_2O emissions from slurry and mineral N fertiliser applied to grassland. pp 201-209 In: Gaseous Nitrogen Emissions from Grasslands (Eds S. C. Jarvis, B. F. Pain). CAB International.

Meixner, F.X. 1994. Surface exchange of odd nitrogen oxides. Nova Acta Leopoldina NF70 **288**, 299-348.

Moisier, A. R., Duxbury, J. M., Freney, J. R., Heinemeyer, O., Minami, K. 1996. Nitrous oxide emissions from agricultural fields - assessment, measurement and mitigation. Plant and Soil **181**, 95-108

MÜller, C., Kammann, C., Burger, S., Ottow, J. C. G., Grunhage, l., Jager, H. J. 1997. Nitrous oxide emission from frozen and during thawing of frozen grassland soil. In: Proceedings of the 7th International N_2O workshop, Cologne,April 1997.

O'Toole, P., Morgan, M. A. 1988. efficiency of fertiliser urea: the Irish experience. pp.191-206 In: Jenkinson, D. S. Smith, K. A. (Editors) Nitrogen Efficiency in Agricultural Soils. Elsevier Applied Science, London.

Pain, B. F., Weerden, T. Van der., Jarvis, S. C., Chambers, B. J., Smith, K. A., Demmers, T. G. M., Phillips, V. R. 1997. Ammonia Emissions Inventory for the UK. Institute of Grassland and Environmental Research, (IGER), Okehampton, UK.

Patel, S. K., Panda, D., Mohanty, S. K 1989. Relative ammonia loss from urea-based fertilisers applied to rice under different hydrological situations. Fertiliser Research **19(2)**,113-120.

Recous, S., Fresnau, C., Faurie, G., Mary, B. 1988. The fate of labelled ^{15}N urea and ammonium nitrate applied to a winter wheat crop. I. Nitrogen transformations in the soil. Plant and Soil **112**, 205-214.

Remede, A., Conrad, R. 1991. Role of nitrification and denitrification for NO metabolism in soils. Biogeochemistry **12**, 189-205

Ryden, J. C., Whitehead, D. C., Lockyer, D. R., Thompson, R. B., Skinner, J. H., Garwood, E.A. 1987. Ammonia emissions from grassland and livestock production systems in the UK. Environmental Pollution **48**,173-184.

Schøjrrring, J. K. 1991. Ammonia emissions from the foliage of growing plants, pp 267-292 In: Trace gas emissions by plants. (Eds. T. D. Sharkey, E. A. Holland and H. A. Mooney),. Academic Press, San Diego.

Skiba, U., Hargreaves, K. J., Fowler, D., Smith, K. A. 1992. Fluxes of nitric and nitrous oxides from agricultural soils in a cool temperate climate. Atmospheric Environment **26 (14)**, 2477-2488.

Skiba, U., Fowler, D., Smith, K. A. 1997. Nitric oxide emissions from agricultural soils in temperate and tropical climates: Sources, controls and mitigation options. Nutrient Cycling in Agroecosystems **48**, 75-90.

Sommer, S. G., Jensen, C. 1994. Ammonia volatilization from urea and ammoniacal fertilisers surface applied to winter wheat and grassland. Fertiliser Research **37**, 85-92.

Stohl, A., Williams, E., Wotawa, G., Kronup-Kolb, H. 1996. A European Inventory of soil nitric oxide emissions and the effect of these emissions on the photochemical formation of ozone. Atmospheric Environment **30(22)**, 3741-3755.

Sutton, M. A., Burkhardt, J. K., Geurin, D., Fowler, D. 1995a. Measurement and modelling of ammonia exchange over arable croplands. pp 71-80 In: Heij, G. J. and J. W. Erisman (Editors) Acid rain research, do we have enough answers? Studies in Environmental Science 64, Elsevier Science BV.

Sutton, M. A., Pitairn, C. E. R., Fowler, D. 1993. The exchange of ammonia between the atmosphere and plant communities. Advances in Ecological Research **24**, 301-393.

Sutton M. A., Place C. J., Eager M., Fowler D., Smith R. I. 1995b. Assessment of the magnitude of ammonia emissions in the United Kingdom. Atmospheric Environment **29**, 1393-1411.

Sutton, M. A., Nemitz, E., Fowler, D., Wyers, G. P., Otjes, R., San Jose, R., Moreno, J., Schjørring, L. K., Husted, S., Meixner, F. X., Ammann, C., Neftel, A., Gut, A. 1996. The EXAMINE Project: Exchange of Atmospheric Ammonia with European Ecosystems. pp 155-161. In : Proceedings of the EUROTRAC Symposium '96. (Eds P. M. Borrell, P. Borrell, T Cvitaš, K. Kelly & W. Seiler). Computational Mechanics Publications, Southampton, UK.

UKRGIAN, 1994. Impacts of Nitrogen deposition in Terrestrial Ecosystems (INDITE). Report of the United Kingdom Review Group on Impacts of Atmospheric Nitrogen. 110 pp. Department of the Environment, London.

Velthof, G. L., Brader, A. B., Oenema, O. 1996. Seasonal variations in nitrous oxide losses from managed grasslands in the Netherlands, Plant and Soil **181**, 263-274.

Vlek, P. L. G., Stumpe, J. M. 1978. Effects of solution chemistry and environmental conditions on ammonia volatilization losses from aqueous systems. Soil Science Society of America Journal **42**, 416-421

Weerden, T. J. van der, Jarvis, S.C. 1997. Ammonia emission factors for N-fertilisers applied to two contrasting grassland soils. Atmospheric Pollution **95(2)**,205-211.

Whitehead, D. C., Lockyer, D. R. 1989. Decomposing grass herbage as a source of ammonia in the atmosphere. Atmospheric Environment **23**, 1867-1869.

Whitehead D. C., Raistrick, N. 1990. Ammonia volatilization from five nitrogen compounds used as fertilisers following surface application to soils of differing characteristics. Journal of Soil Science **41**, 387-394.

Whitehead, D. C., Raistrick, N. 1993. The volatilization of ammonia from cattle urine applied to soils as influenced by soil properties. Plant and Soil **148**, 43-51.

Williams, E. J., Guenther, A., Fehsenfeld, F. C. 1992. An inventory of nitric oxide emissions from soils in the United States. Journal of Geophysical Research **97**, 7511-7519.

Yamulki, S., Goulding, K. W. T., Webster, C. P., Harrison, R. M. 1995. Studies on NO and N_2O fluxes from a wheat field. Atmospheric Environment **29(14),** 1627-1635.

Yienger, J. J., Levy, H. 1995. Empirical model of the global soil-biogenic NO_x emissions. Journal of Geophysical Research. **100**, 11447 - 11464.

18 BIBLIOGRAPHY

See in particular: Asman (1992), Bouwman (1996) ECETOC (1994), Holtan-Hartwig and Bøckman (1994), IPPC/OECD (1995), Skiba et al. (1997) and Sutton et al. (1995b).

19 RELEASE VERSION, DATE AND SOURCE

Version: 3.1

Date: 3 February 1999

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SNAP CODE: **100201**
100202
100203
100204
100205

SOURCE ACTIVITY TITLE: **CULTURES WITHOUT FERTILISERS**
Permanent Crops
Arable Land Crops
Rice Field
Market Gardening
Grassland

NOSE CODE: **110.02.01**
110.02.02
110.02.03
110.02.04
110.02.05

NFR CODE: **4 D 1**
4 C

1 ACTIVITIES INCLUDED

This chapter considers the emissions of ammonia (NH_3), nitrous oxide (N_2O), other oxides of nitrogen (NO_x) and volatile organic compounds (VOCs). Cultures without fertilisers are soils cultivated for crop production and grasslands, for cutting and grazing, which are not given N-fertiliser (e.g. legumes and grass/clover swards). This includes some grass in hill-land, which is grazed by livestock, as well as lowland grass that only supports small numbers of animals and does not require fertiliser-N. Emissions from the crops and their decomposing residues are also considered. Persistent Organic Pollutants are dealt with separately under SNAP Code 100600, Use of Pesticides.

Emissions following animal manure application are considered in SNAP Code 100500, Manure Management.

This chapter is a development of chapter ag100100 (EEA 1996) which dealt with cultures both with and without fertilisers. Cultures with Fertilisers are now considered in chapter 100100. Reference may be made to that chapter for further discussion of some of the topics covered here.

In this chapter 100206 includes ‘Set-Aside’ Land.

2 CONTRIBUTIONS TO TOTAL EMISSIONS

The major source of NH_3 emissions in Europe is volalization from livestock excreta. Ammonia may also be emitted from the application of N-fertilisers and from fertilised crops. Emissions from unfertilised crops are usually considered to be negligible, althought there may be some emissions from N-rich legumes.

The greatest proportion of N_2O emitted by agriculture is considered to be by soil processes following the application of N fertilisers and animal manures to land. However N_2O emissions may also take place during the breakdown of crop residues and mineralisation of excretal-N deposited during grazing and soil organic matter. Emission of N_2O may also occur place following the deposition of other N compounds (NH_3 and NO_x) to unfertilised soils.

Soils and crops are regarded as a net sink for most NO_x compounds. However NO may be released from soils during the mineralisation of N from incorporated crop residues and soil organic matter followed by nitrification. Only NO emissions are therefore discussed. At present estimates of the proportion of these emissions that arise from cultures without fertilisers are extremely uncertain.

Table 2.1: % Contribution of total emissions of the CORINAIR94 Inventory (28 Countries) from cultures without fertilisers.

SNAP code	**SO_2**	**NO_X**	**NMVOC**	**CH_4**	**CO**	**CO_2**	**N_2O**	**NH_3**
100200	-	0.2	0	1.4	-	-	1.5	0.3

0 = emissions are reported, but the exact value is below the rounding limit (0.1 %).
- = no emissions are reported

As can be seen from Table 2.1, emissions of NH_3, NO and VOCs are all < 1% of current total emission estimates. These do not therefore require a methodology for calculation. However given current uncertainties over the magnitude of emissions from unfertilised crops and grass, some information is given in this chapter. This summarises current understanding and uncertainties.

3 GENERAL

3.1 Description

3.1.1 Ammonia

The direct emissions of NH_3 that have been measured from crops have been attributed to enrichment of the apoplast with NH_4^+ following addition of fertiliser-N (Sutton et al. 1995). There is very little information on ammonia emissions from cultures without fertilisers. Significant emissions are not expected from unfertilised crops (with the exception of legumes).

Crops of agricultural legumes, while not given fertiliser-N, have been estimated to fix amounts of N as great, or greater than applied as fertiliser to agricultural crops (Sylvester-Bradley 1993). Thus emissions of NH_3 may be expected to be similar to those from fertilised agricultural crops (e.g. 0-15 kg $ha^{-1}yr^{-1}$, Sutton et al. 1995). Data on NH_3 fluxes over legume crops are sparse. Dabney and Bouldin (1985) measured a small net emission of *c.* 2 kg ha^{-1} yr^{-1} NH_3-N from an alfalfa crop. Harper et al. (1989) found net depositions of 0.4 - 3.1 kg ha^{-1} yr^{-1} from soybeans. Lemon and van Houtte (1980) measured both emission and deposition fluxes over soybeans.

Some recent results (R. Harrison, ADAS Boxworth, pers. comm.) also suggested no net emission over the growing season. However in that study small (1-2 kg N ha^{-1}) emissions early in the season were balanced by deposition (2-3 kg N ha^{-1}) later in the season. This deposition may have been a consequence of grazing activity in the locality. The possibility remains that agricultural legume crops, in predominantly arable areas, may emit small amounts of NH_3. Ammonia fluxes are also bi-directional over fertilised arable crops. These few data suggest that, at present, only an approximate, indicative emission factor for cultivated legumes can be made.

Measurements of NH_3 fluxes over unfertilised grassland have usually shown net deposition of NH_3 (Sutton et al. 1993). Whitehead and Lockyer (1989) measured emissions only from grass foliage with a high-N content where large amounts of fertiliser-N had been applied.

Ammonia emissions from unfertilised grass, grazed by livestock, have been made by Jarvis et al. (1989 and 1991) and Ledgard et al. (1996). Jarvis et al. (1989) found annual NH_3 emissions of 7 kg ha^{-1} N from a grass/clover pasture grazed by beef cattle. This was *c.* 4% of the estimated N fixation by the clover (160 kg N ha^{-1} yr^{-1}), and *c.* 70% of NH_3 emissions from grazed grassland given 210 kg ha^{-1} N yr^{-1}. Jarvis et al. (1991) measured NH_3 emissions from pastures grazed by sheep, including an unfertilised clover monoculture. Emissions of NH_3 from the unfertilised grass/clover pasture (2kg N ha^{-1} yr^{-1}) were less than from an unfertilised grass field (4 kg ha^{-1} yr^{-1}), whilst emissions from the pure clover pasture (11 kg N ha^{-1} yr^{-1}) were greater than from grassland given 420 kg N ha^{-1} yr^{-1}. These losses were smaller (by a factor of 3) than from pastures grazed by cattle (Jarvis et al. 1989). Ledgard et al. (1996) measured an annual NH_3 emission of 15 kg/ha from unfertilised grass/clover grazed by dairy cattle. There are considerable uncertainties in generalizing from these limited data. Differences in emission are likely to be the result of variation in temperature, soil type and livestock type. In addition, if unfertilised grassland is cut and left in the field for an extended period, decomposition may result in some emission.

3.1.2 Nitrous Oxide

The methodology adopted by the IPCC may be used to calculate emissions of N_2O from cultures without fertilisers as the sum of, i) direct soil emissions and, ii) indirect emissions. Direct soil emissions from cultures without fertiliser may be the result of biological N fixation, excreta of grazing animals, crop residue incorporation and soil cultivation. Indirect emissions may arise as a consequence of atmospheric deposition of NH_3 and NO_x to unfertilised soils.

In soil N_2O is produced predominantly by nitrification (the oxidation of ammonium (NH_4^+) to nitrate (NO_3^-), and denitrification (the reduction of NO_3^- to gaseous forms of N : N_2O and N_2). The rate of N_2O production is primarily dependent on the availability of mineral N in the soil (Bouwman 1996). The cultivation of soils, grazing by livestock and incorporation of crop residues are likely to increase soil mineral N concentrations and hence N_2O emission (e.g. Flessa and Beese 1995). Moreover large emissions of N_2O may take place following the thawing of frozen soils (Kaiser et al. 1997).

The magnitude of direct N_2O emissions may be expected to vary with a range of soil and environmental factors. More work is needed on partitioning of N_2O production between nitrification and denitrification. Incorporation of N-rich (e.g. leguminous) residues into moisture-retentive soils produces greater N_2O emissions than from free-draining soils (Skiba et al. 1992). Incorporation into warm soils is also likely to lead to greater emissions than from soils which are cold. Rapid crop growth, and demand for NO_3-N, may be expected to reduce N_2O emissions by reducing the pool of mineral N available for denitrification. Such soil and environmental factors are also likely to influence the magnitude of indirect N_2O emissions following atmospheric deposition of NH_3 and NO_x.

3.1.3 Nitric Oxide

Nitric oxide (NO) may be emitted from unfertilised soils as a consequence of nitrification or denitrification. If soils are maintained above pH 5.0, NO emission is likely to be mainly from nitrification (Remde & Conrad 1991; Skiba et al.1997). Increased nitrification is likely to occur following soil cultivation and incorporation of crop residues. Activities such as tillage and incorporation were considered to increase NO emissions by a factor of 4 (Skiba et al. 1997), for periods of between 1 and 3 weeks.

The main determinant of NO production in agricultural soils is mineral N concentration (Skiba et al 1997); which in unfertilised cultures is increased by residue incorporation and cultivation. As a first approximation, 0.3% of N inputs may be expected to be lost as NO, as per SNAP Code 100100, Cultures with Fertilisers. Thus a knowledge of the available N concentration, and mineralisation rate of crop residues, could provide an estimate of soil NO emissions following cultivation.

However, very little data are available on emissions of NO from unfertilised soils that may be used as a basis for compiling an inventory.

3.1.4 Volatile Organic Compounds

Volatile Organic Compounds (VOCs) are defined as “...all those organic compounds, other than methane, which can produce photochemical oxidants by reaction with nitrogen oxides in the presence of sunlight”.

Three categories of sources may be distinguished:

(1) Activities that emit VOCs by combustion or evaporation;
(2) Land clearing, including burning;
(3) Biogenic processes.

The primary sources in the agricultural sector are:

(1) Burning stubble and other plant wastes;
(2) The use of organic solvents in pesticide production;
(3) Anaerobic degradation of livestock feed and animal excreta.

These 3 major sources are dealt with elsewhere. Stubble burning in SNAP Code 100300, emissions from burning other crop residues in SNAP Code 090700 (Open Burning of Agricultural Wastes). Emissions from livestock manures are included in SNAP Code 100500, Manure Management.

The emission of some VOCs may be of benefit to plants to attract pollinating insects. While others may be involved in interactions, be waste products or a means of losing surplus energy (Hewitt and Street 1992). These emissions have been observed to increase when plants are under stress. Factors that can influence the emission of VOCs include temperative and light intensity, plant growth stage, water stress, air pollution and senescence (Hewitt and Street 1992). Emissions of VOCs from plants have usually been associated with woodlands (König et al. 1996). Hewitt and Street (1992) took qualitative measurements of the major grass and crop species in the UK (except for barley, *Hordeum vulgare*). None of the grass species were found to emit isoprene or terpenes. The only crop species producing any significant emissions was blackcurrant (*Ribes nigrum*). However, these workers warned against classifying plants as ‘non-emitters’ on the basis of limited measurements, as plant growth stage had been shown to be an important factor in emission.

Hewitt and Street (1992) concluded that only c. 700 plant species, mainly from N. America, had been investigated as isoprene or monoterpene emitters. Few of these were agricultural crops, and quantitative data was available for only a few species. Many measurements had been made at temperatures higher than those prevailing in N and W Europe.

3.2 Definitions

Animal Manures. Animal excreta deposited in houses and on yards, collected, either with bedding or without, to be applied to land.

Livestock excreta. Animal excreta deposited at any time, including while grazing.

Unfertilised agricultural grassland. Grassland, to be used for either cutting grass for conservation, grazing or both, to which synthetic N-fertilisers have **not** been applied. Phosphorus or potassium fertilisers may be used.

*Crop residues.*The unharvested parts of crops that are left on the field and ultimately incorporated into the soil.

Hill Land. grassland in the hills or uplands that is used for grazing agricultural livestock.

3.3 Controls

3.3.1 Ammonia

No measures have so far been proposed to reduce NH_3 emissions from cultures without fertilisers. There are some possible suggestions. The area of legumes could be reduced. However the consequence may be an increase in the area of crops requiring fertiliser-N. Ammonia emissions from these may not be less than from legumes. Pure clover pastures may be replaced by mixed grass/clover. This is unlikely to be of much practical significance, as pure clover pastures are uncommon.

3.3.2 Nitrous Oxide

Nitrous oxide emissions may arise following the incorporation of N-rich crop residues into warm moist soil. A control technique may, therefore, be to avoid incorporating residues in late summer/early autumn and delaying incorporation until late autumn where succeeding crops are to be sown before the onset of winter. This will also have the advantage of reducing the potential for NO_3^- leaching. However leaving N-rich crop residues (e.g. from legumes) on the soil surface will probably give rise to NH_3 emissions as they senesce.

3.3.3 Nitric Oxide

In view of the limited information on the loss of NO from unfertilised soils, no specific control measures are proposed at this stage. However, any measure that reduces mineral N production and input to the soil, as discussed in section 3.3.2, will also reduce loss of NO.

3.3.4 Volatile Organic Compounds

To reduce emissions of VOCs, crop residues should be removed from the field (to be used for animal feed and bedding) rather than be disposed of by burning.

4 SIMPLER METHODOLOGY

4.1 Ammonia

Since legumes are the only arable crops regarded as sources of NH_3 in cultures without fertilisers, a simple estimate of NH_3 emissions may be made by multiplying the known area of legumes with an estimated emission factor of 1 kg ha^{-1} yr^{-1}.

The following emission factors (kg NH_3-N ha^{-1} yr^{-1}) are proposed for all unfertilised pastures grazed by cattle, and for lowland pastures grazed by sheep :

Grass/clover,	Cattle 7,	Sheep 2;
Unfertilised grass,	Cattle 4,	Sheep 4.

These emission factors are taken from studies of grazing emissions by Jarvis et al. (1989 and 1991). Greater emission factors from unfertilised grass than from grass/clover swards, may appear contrary to expectations. Jarvis et al. (1991) were unable to fully explain this observation, but suggested the different crop canopy structure of grass/clover pastures might reduce NH_3 losses.

The use of the above factors also gives greater apparent NH_3 emissions than are estimated by additions of fertiliser-N of up to c. 200kg N ha^{-1} in Chapter 100100, Cultures with fertilisers. These anomalies emphasise the lack of data available on NH_3 emissions from unfertilised, grazed grass, and hence the uncertainty of this component of the Emission Inventory.

Hill-land grass grazed by sheep, is not regarded as a net source of NH_3 emission over the year (e.g. Sutton et al.1993).

4.2 Nitrous Oxide

Following the IPCC methodology (IPCC/OECD 1997), N_2O emissions from unfertilised agricultural soils may be calculated as the sum of:

i. direct soil emissions (1.25% of N inputs are emitted as N_2O-N); (where N inputs are from biological N fixation and crop residues). See IPCC Worksheet 4-5, sheet 1;

ii. direct N_2O emissions from cultivation of histosols (IPCC Worksheet 4-5, sheet 2);

iii. direct soil emissions (2% of N inputs) from grazing animals (IPCC Worksheet 4-5, sheet 3);

iv. indirect emissions following deposition of NH_3 and NO_x (1% of N is subsequently re-emitted as N_2O), or leaching and run-off (2.5% of N leached or run-off, IPCC Worksheet 4-5, sheets 4 and 5).

These input data can be estimated from FAO data (see IPCC/OECD 1997) (Table 4.1).

The default emission factors for the above are given in Table 4.2. More detail may be obtained from IPCC Worksheet 4-5, sheets 1-5.

Prior to estimation of direct N_2O emissions, excretal N returns are reduced by 20% to allow for N lost as NH_3. Information on N excretion by livestock is given in SNAP Code 100500, Manure Management. However those values, may be an overestimate for unfertilised grass as they are averages across a range of production systems and both fertilised and unfertilised grassland.

The N_2O emission may be calculated as :

$$F_{N_2O\text{-}N} = 0.0125 * \text{'net' N inputs} + 0.02 * \text{'net' N inputs from grazing} + 0.01 * (NH_3 + NO_x\text{-N emissions to atmosphere}) + 0.025 * \text{N (leached and/or run off)} \quad (1)$$

where units are generally expressed as kg N ha^{-1} yr^{-1}.

In the case of organic soils (histosols) an additional emission of 5 kg N ha^{-1} yr^{-1} is added (Table 4.2).

Table 4.1: Summary of IPCC source categories (IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2: Workbook, 1997) to be reported as CORINAIR sub-sectors for agriculture.

CORINAIR SUB-SECTOR (snap code)	**IPCC N_2O SOURCE (IPCC WORKBOOK WORKSHEET**
Cultures with/without fertilisers (100100.100200)	– Direct soil emission due to N-inputs excluding manure (4-5, sheet 1, excluding animal waste F_{aw}) – Direct soil emissions due to histosol cultivation (4-5, sheet 2) – Direct soil emissions from grazing animals; pasture, range & paddock (4-5, sheet 3) – Indirect emissions due NH_3 and NO_x emissions from synthetic fertiliser use and grazing animals (4-5, sheet 4, excluding animal waste used as fertiliser) – Indirect emissions due N leaching/runoff from synthetic fertiliser use and grazing animals (4-5, sheet 5, excluding animal waste used as fertiliser
Manure Management (100500)	– Manure management: 6 waste management systems (4-1, sheet 2, excluding pasture, range & paddock) – Direct soil emissions due to manure N-inputs excluding grazing animals (4-5, sheet 1, row for animal waste Faw only) – Indirect emissions due NH_3 and NO_x emissions from animal waste excluding grazing animals (4-5, sheet 4, animal waste used as fertiliser only) – Indirect emissions due N leaching/runoff from animal – waste excluding grazing animals (4-5, sheet 5, animal waste used as fertiliser only)

The default values used by IPCC (IPCC/OECD 1997) for the above are given in Table 4.2.

The IPCC guidelines estimate direct soil emissions as a fraction of N input to soils, excluding NH_3 emissions. This ‘net’ N input is calculated for N deposited during grazing as:

$$\text{‘net’ N input (kg N ha}^{-1}\text{)} = \text{Excretal-N input (kg N ha}^{-1}\text{)} * 0.8 \qquad (2)$$

To calculate N_2O emissions from N deposited during grazing, the ‘net’ N input is multiplied by the emission factor 0.02 kg N_2O-N per kg ‘net’ excretal N input.

$$F N_2O \text{ (grazing)} = \text{‘net’ grazing N input (kg N ha}^{-1}\text{)} * 0.02 \text{ kg } N_2O\text{-N kg N input}^{-1} \qquad (3)$$

Discussion of the suitability of this estimate is given in 4.2 of SNAP Code 100100.

Table 4.2: Default emission factors for N_2O emissions from cultures without fertiliser

SOURCE OF N_2O	EMISSION FACTOR
Direct soil emissions N inputs (crop residues and biological N fixation). #Excretal-N deposited during grazing.	 0.0125 kg N_2O-N kg N input^{-1} 0.02 kg N_2O-N kg ‘net’ N input^{-1}
Cultivation of histosols.	5 kg N_2O-N ha^{-1}.
Indirect emissions Emission of NH_3 and NO_x	 0.010kg N_2O-N kg^{-1} NH_3-N and NO_x-N deposited
N Leaching and runoff.	0.025 kg N_2O-N kgN^{-1} leached or lost by runoff.

[#] Manure N inputs, other than from animals during grazing. are dealt with in SNAP Code 100500, Manure Management.

4.3 Nitric Oxide

An estimate of the amount of crop residues, together with their N concentrations, returned to unfertilised soils, together with an estimate of excretal-N deposited during grazing would provide estimate of NO emissions. Assuming 0.3% of the N returned to the soil is emitted as NO.

5 DETAILED METHODOLOGY

5.1 Ammonia

To provide a more detailed methodology it would be necessary to distinguish between different legume species.

Where data are available on the areas of legumes under cultivation and the extent of typical N fixation by each crop type, national NH_3 emission from this source may be approximately estimated as:

Legume emission = sum all legume species (0.01 * species N fixation * area of species)= (kg N ha^{-1} year^{-1}).... (4)

Where information on average N fixation rates for different legume species is unavailable for a country, 100 kg N ha^{-1} year^{-1} may be used as a first estimate.

Further detail may be provided if estimates are available of NH_3 emissions from crops (e.g. hay), or unfertilised crop residues left on the surface. The effects of different climates on NH_3 emissions both from unfertilised crops, and from their residues, needs to be known. However emissions from unfertilised cultures are likely to be small in relation to emissions from livestock husbandry.

5.2 Nitrous Oxide

No more detailed methodology is proposed for estimating emissions of N_2O. However countries may use their own estimates for any step in the IPCC method if this will increase precision. In particular countries are encouraged to estimate NH_3 losses using the methods described in this chapter, rather than the IPCC default values.

5.3 Nitric Oxide

Consideration of the data available suggest that NO emissions may vary substantially according to the prevailing soil moisture regime. Temperature is also considered to have a significant effect on NO emissions. As there is so little information on soil NO emissions from cultures without fertilisers, it is not appropriate to provide a detailed methodology.

6 RELEVANT ACTIVITY STATISTICS

Information is required on the areas of legumes cultivated and by crop type for the more detailed approach, as well as the area of unfertilised grassland grazed by livestock, and an estimate of N deposited in excreta during grazing.

Information may also be required on the amounts and N concentrations of crop residues returned to the soil. This information may be obtained from national statistics on crop production. The area of organic soils (histosols) under cultivation is also useful. Finally, information is needed on deposition of NH_3 and NO_x to soils.

Where spatially disaggregated inventories of unfertilised culture emissions are required (Section 12), information on the spatial distribution of different legume and other unfertilised crops are required. The distribution of cultivated, but unfertilised organic soils (histosols) will also be needed).

Table 6.1: Summary of activity statistics which may be required for the simple and detailed methodologies.

Activity Statistic		Source
Amount and N concentration of crop residues	By crop type	FAO, See IPCC/OECD (1997)
Amount and N concentration of animal excreta deposited during grazing	By Livestock type	SNAP Code 100500, Manure Management
Area of cultivated histosols		FAO, See IPCC/OECD (1997)
Atmospheric emissions of NH_3 and NO_x		ETCAE, (1997)
N lost from soils by leaching and runoff		FAO, See IPCC/OECD, (1997)

7 POINT SOURCE CRITERIA

Ammonia, N_2O, NO and VOC emissions from cultures without fertilisers should be treated as area sources.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

The emission factors for NH_3 losses from cultures without fertilisers are treated as kg N ha^{-1} of leguminous crops and grazed, unfertilised grassland. For N_2O, losses are kg N_2O-N kg N^{-1} returned to the soil in crop residues and excreta deposited during grazing, or N deposited from the atmosphere, or lost by leaching or runoff. Losses of N_2O from cultivated organic soils (histosols) are expressed as kg N ha^{-1}.

Table 8.1: Spreadsheet for calculating nitrous oxide emissions from cultures without fertilisers according to the simple methodology.

	A	**B**	
N input	N emission kg	N input, kg N yr^{-1}	N_2O emission kg N_2O yr $^{-1}$ (A * B * 44/28)
Crop residues N	0.0125		
Excretal-N deposited during grazing			
Emission of NH_3 Emission of NO_x N lost by leaching or runoff	0.010 0.010 0.025		
	kg ha^{-1}	**Area (ha)**	
Cultivation of histosols	5		

9 SPECIES PROFILES

As with forest NMVOC emissions, biogenic emissions from grasslands consist of a wide variety of species, including isoprene, monoterpenes (alpha-pinene, beta-pinene, limonene, etc), and ‘other’ VOC. The ‘other’ VOC (OVOC) species consist of a large number of oxygenated compounds (alcohols, aldehydes, etc.), and have proven difficult to quantify in atmospheric samples. Progress in quantification of OVOC from European vegetation has been made recently (König et al. 1996), although many more measurement data will be required before reliable attempts to inventory specific OVOC can be made.

10 UNCERTAINTY ESTIMATES

10.1 Ammonia

The main uncertainty lies in the magnitude of emission factors for unfertilised grassland and leguminous crops, rather than the areas of unfertilised crops under cultivation, which is probably accurate in most countries to better than ±10%. The overall uncertainty is at least a factor of 5.

10.2 Nitrous Oxide

The processes controlling the emission of N_2O from soils are reasonably well understood but their interactions and hence estimates of emission have not yet been accurately modelled.

The magnitude of crop residues and their N contents are only likely to be accurate to within ± 25%. Wet deposition of N may be estimated to ± 20%, but dry deposition of NH_3 to no more than ± 50% (UKRGIAN 1994). As for NH_3 the main uncertainty lies on the generalisation of emission factors, which are perhaps greater than a factor of 5.

10.3 Nitric Oxide

Much less information is available on factors determining losses of NO from soils. (Available N, temperature and soil moisture are likely to be the main factors). In view of the paucity of data, the overall uncertainty is likely to be greater than a factor of 5.

10.4 Volatile Organic Compounds

Estimates of biogenic VOC emissions for the UK range from 38-211 kt yr^{-1} total VOCs. Between *c*. 10 and 59 kt yr^{-1} appear to be of agricultural origin. This compares with the CORINAIR94 estimate of only 2 kt yr^{-1} for SNAP Code 100100 or < 2% of emission from agriculture and forestry. Thus the emission estimates appear to be uncertain by a factor of 30.

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

11.1 Ammonia

Little data is available on NH_3 emissions from leguminous crops, and it does not allow distinction to be made between species. Measurements of emissions from crop residues after harvest is also lacking. The majority of data on NH_3 emissions from grazed grassland have been made on NW Europe. Emission may be greater in drier and warmer areas, e.g. S. Europe. While more work on the development of mechanistic models, which take into account both physicochemical and biological processes is desirable, the primary interest is in understanding atmospheric budgets rather than in the definition of net emissions. It should also be recognised that there is a very large uncertainty in NH_3 emissions in relation to climate and more work is necessary, in particular in Southern and Eastern European conditions.

11.2 Nitrous Oxide

Current estimates of N_2O emissions are also limited by the use of fixed emission factors. More work needs to be done in the development of process-based models that will allow greater discrimination to be made between soils with different moisture regimes, and between areas of different climate. The localised very high inputs of N and C, from animal excreta, are likely to stimulate N_2O emissions.

Estimates of indirect emissions of N_2O are dependent on accurate estimates of N deposition and N leaching and runoff as long as the uncertainties in these estimates are large, then so too will be estimates of indirect N_2O emissions.

11.3 Nitric Oxide

Very little information is available on NO emissions from any of the aspects discussed in this section. More work on NO emissions from unfertilised grassland, land cultivated with legumes and as a result of crop incorporation is particularly desirable. Localised, very high inputs of N and C from animal excreta, are likely to stimulate NO emissions.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

12.1 Ammonia

Census data on the location of unfertilised crops and grassland, and particularly the distribution of legume crops may be used.

12.2 Nitrous Oxide

Direct emissions may be spatially disaggregated using census data on the distribution of different unfertilised crops and grassland, together with estimates of the N returned in their residues. Data on the distribution of cultivated, unfertilised organic soils (histosols) may also be included to improve spatial disaggregation. Indirect emissions may also be spatially disaggregated if spatial data is available for N deposition and also for N leaching and run off.

12.3 Nitric Oxide

Emissions may be spatially disaggregated using census data on the distribution of different unfertilised crops and grassland, together with estimates of N returned in their residues.

12.4 Volatile Organic Compounds

In the absence of specific data for VOC emissions from different agricultural crops, there appears to be little scope at present for spatially disaggregating VOC emissions.

13 TEMPORAL DISAGGREGATION CRITERIA

13.1 Ammonia

Almost no information is available to generalise on temporal disaggregation of NH_3 from unfertilised crops. Crop emissions are likely to be greatest during crop senescence and from residues left on the soil surface. Dabney and Bouldin (1985) observed a marked seasonal variation in NH_3 fluxes. Emissions were approximately in balance for most of the year, but emissions were greater in the 10 days after the crop was cut for hay. Harper et al. (1989) noted that absorption of NH_3 took place while the soybean crop was well-supplied with water, while emission of NH_3 tool place during drought. Such losses are likely to vary greatly from year to year depending upon environmental conditions. Emissions of NH_3 from grazed grassland will largely take place while animals are grazing, although some emission is likely for a period after the animals have left the field.

13.2 Nitrous Oxide

Some data may also be available on the timing of incorporating crop residues. However, until process-based models have been developed and validated it will not be possible to take account of fluxes of N_2O emission that take place when soil mineral N concentrations, soil water regimes and soil temperature combine to produce favourable conditions for denitrification and N_2O emission by nitrification.

Data will be available, for some countries at least, on the temporal variation in N deposition and N leaching and run off.

As for NH_3, losses may vary greatly from year to year, depending upon weather conditions.

13.3 Nitric Oxide

Losses of NO take place mainly as a consequence of nitrification. Peaks in NO emission are, therefore, likely in the first 1 to 3 weeks following incorporation of crop residues and tillage of soils. Data on all these should be available, for some countries at least. At present, however, there is insufficient data on NO emissions to quantify these effects. Ultimately, as the mechanisms of NO production become better understood, climatic data may also be utilised to assess when soil and weather conditions are favourable for nitrification and hence NO production. In common with NH_3 and N_2O, emissions may vary greatly from year to year, depending upon weather conditions.

13.4 Volatile Organic Compounds

Emissions of VOCs are likely to differ according to crop growth stage and weather conditions. Some temporal disaggregation may be possible, if seasonal variations in emissions by non-agricultural plants can be assumed to be valid for unfertilised crops.

14 ADDITIONAL COMMENTS

Where more detailed methodologies than those described here are used by countries, a detailed description should be given of the methodology used, and comparison made to the results of the methodology described here.

15 SUPPLEMENTARY DOCUMENTS

The main supplementary documentation required for applying the estimates in this chapter are details of spatially disaggregated legume crop and unfertilised grass distributions.

16 VERIFICATION PROCEDURES

There are no direct methods to evaluate total inventory estimates of NH_3 emissions from unfertilised croplands, and verification is dependent on laboratory and micrometeorological field studies of emissions from example situations. In particular, many studies have focused on laboratory measurements and there is a need to provide long-term field measurements using micrometeorological techniques to estimates fluxes over a range of crop types in different climates.

Emissions of N_2O, NO and VOCs cannot be verified except by field studies of emissions from example situations. There is a need to long-term field measurements to estimate fluxes over a range of crop types and climates.

17 REFERENCES

Anastasi, C., Hopkinson, L., Simpson, V. J. (1991). Natural Hydrocarbon emissions in the United kingdom. Atmospheric Environment **25A**, 1403-1408.

Bouwman, A. F. 1996. Direct emission of nitrous oxide from agricultural soils. Nutrient Cycling in Agroecosystems **46**, 53-70.

Dabney, S. M., Bouldin, D.R. (1985) Fluxes of ammonia over an alfalfa field.

Agronomy Journal **77**, 572-578.

EEA (1996). Atmospheric Emission Inventory guidebook. (Ed G. McInnes). European Environment Agency, Copenhagen.

ETCAE (1997). CORINAIR 94 Summary Report - European Emission Inventory for Air Pollutants. European Environment Agency, Copenhagen.

Flessa, H., Beese, F. 1995. Effects of sugar beet residues on soil redox potential and N_2O emission. Soil Science Society of America Journal **59**, 1044-1051.

Harper, L. A., Giddens, J. E., Langdale, G. W. & R. R. Sharpe. (1989) Environmental effects on nitrogen dynamics in soybean under conservation and clean tillage systems. *Agronomy Journal* **81,** 623-631.

Hewitt, C. N., Street, R. A. 1992. A qualitative assessment of the emission of non-methane hydrocarbons from the biosphere to the atmosphere in the U.K. : present knowledge and uncertainties. Atmospheric Environment 26A, 3069-3077.

Holtan-Hartwig L. and Bφckman O.C., 1994. Ammonia exchange between crops and air. Norwegian J. Agric. Sci. supplement No. 14. 41 pp.

IPPC/OECD 1995. Nitrous oxide and carbon dioxide in agriculture. OECD/IPPC/IEA Phase II development of IPPC guidelines for national greenhouse gas inventory methodology. Workshop Report, December 4-6, 1995. OECD, 2 rue André Pascal, Paris.

Jarvis, S. C., Hatch, D. J., Lockyer, D. R. (1989). Ammonia fluxes from grazed grassland : annual losses from cattle production systems and their relation to nitrogen inputs. Journal of Agricultural Science, Cambridge **113**, 99-108.

Jarvis, S. C., Hatch, D. R., Orr, R. J., Reynolds, S. E. 1991. Micrometeorological studies of ammonia emission from sheep grazed swards. Journal of Agricultural Science, Cambridge 112, 205-216.

Kaiser, E. A., Kohrs, K., Kuecke, M., Schnug, E., Munch, J. C., Heinemeyer, O. 1997. N_2O emissions from different arable crops-importance of N fertilisation levels. In : Proceedings of the 7th International N_2O Workshop, Cologne, April 1997.

König, G., Brunda, M., Puxbaum, H., Hewitt, C. N., Duckham, S. C., Rudolph, J. 1995. Relative contribution of oxygenated hydrocarbons to the total biogenic VOC emissions of selected mid-European agricultural and natural plant species. Atmospheric Environment **29(8),** 861-874.

Ledgard, S. F., Clark, D. A., Sproson, M. S., Brier, G. J., Nemaia E. K. K. 1996. Nitrogen losses from a grazed dairy pasture, as affected by nitrogen fertiliser application. Proceedings of the New Zealand Grassland Association **57**, 21-25.

Lemon, E., Van Houtte, R. 1980. Ammonia exchange at the land surface. Agronomy Journal **72**, 876-883.

Remde, A., Conrad, R. 1991. Role of nitrification and denitrification for NO metabolism in soils. Biogeochemistry **12**, 189-205

Skiba, U., Hargreaves, K. J., Fowler, D., Smith, K. A. (1992). Fluxes of nitric and nitrous oxides from agricultural soils in a cool temperate climate. Atmospheric Environment **26 (14)**, 2477-2488.

Skiba, U., Fowler, D., Smith, K. A. (1997). Nitric oxide emissions from agricultural soils in temperate and tropical climates : Sources, controls and mitigation options. Nutrient Cycling in Agroecosytems **48**, 75-90.

Sutton, M. A., Fowler, D., Moncrieff, J. B. (1993). The exchange of atmospheric ammonia with vegetated surfaces. In : Unfertilised vegetation. Quarterley Journal of the Royal Meteorological Society. **119**,1023-1045.

Sutton, M. A., Fowler, D., Hargreaves, K. J., Storeton-West, R. L. (1995). Interactions of NH_3 and SO_2 exchange inferred from simultaneous flux measurements over a wheat canopy. pp.173-190 In: General assessment of biogenic emissions and deposition of nitrogen compounds, sulphur compounds and oxidants in Europe. (Eds Slanina, J., Angletti, G.,Beilke, S.). Proc. joint CEC/BIATEX workshop, Aviero, Portugal, May 1993. Commission of the European Communities, Luxembourg.

Sylvester-Bradley, R. (1993). Scope for more efficient use of fertiliser nitrogen. Soil Use and Management **9(3)**,112-117.

UKRGIAN, 1994. Impacts of Nitrogen deposition in Terrestrial Ecosystems (INDITE). Report of the United Kingdom Review Group on Impacts of Atmospheric Nitrogen.

Whitehead, D. C. & Lockyer, D. R. 1989. Decomposing grass herbage as a source of ammonia in the atmosphere. Atmospheric Environment **23**, 1867-1869.

18 BIBLIOGRAPHY

See in particular: Asman (1992), ECETOC (1994), Holtan-Hartwig and Bøckman (1994), IPPC (1995), Skiba et al (1997) and Sutton et al (1995).

19 RELEASE VERSION, DATE AND SOURCE

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Date: 3 February 1999

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SNAP CODE:

100301
100302
100303
100304
100305

SOURCE SUB-SECTOR TITLE:

STUBBLE BURNING
Cereals
Pulses
Tuber & Root
Sugar cane
Other

NOSE CODE:

110.03.01
110.03.02
110.03.03
110.03.04
110.03.05

NFR CODE:

4 F 1
4 F 2
4 F 3
4 F 4
4 F 5

1 ACTIVITIES INCLUDED

This chapter relates to the emissions of ammonia from stubble burning. This activity is understood to include the burning of crop residues and wastes from crops in situ. Emissions of other pollutants will be provided in subsequent edition of the Guidebook

2 CONTRIBUTION TO TOTAL EMISSIONS

The contribution of agricultural crop waste burning to ammonia emissions on a European scale is currently unknown, but is probably a relatively minor source in comparison to animal wastes. Lee and Atkins (1994) have estimated a contribution of 135 ktonnes NH_3 per year from Western Europe.

This sub-sector is minor source of several pollutants.

Table 1: Contribution to total emissions of the CORINAIR90 inventory (*28 countries*)

Source-activity	**SNAP-code**	**Contribution to total emission [1%]**							
		SO_2	NO_X	NMVOC	CH_4	CO	CO_2	N_2O	NH_3
Stubble Burning	100300	-	0.1	0.2	0.1	0.8	0.1	-	-

0 = emissions are reported, but the exact value is below the rounding limit (0.1 per cent)
- = no emissions are reported

3 GENERAL

Very little information exists on the nature and strength of this source of ammonia emissions. The principal source of the ammonia is from plant nitrogen although some ammonia is likely to originate from the soil underlying the crop wastes combusted. Most of the N from NH_x is released as NH_3 although some is also directly released as NH_4 particulate. Control of this source is effectively be cessation of the activity, the alternative adopted in many countries being that crop wastes and residues are ploughed in.

4 SIMPLER METHODOLOGY

The simple methodology for calculation emission is that outlined by Lee and Atkins (1994), where an emission factor is combined with an activity statistic, i.e. the amount of residue burnt. It is assumed in this methodology that a dry weight of straw from cereal crops is 5 tonnes per ha.

5 DETAILED METHODOLOGY

An improvement on the above can only be achieved by a prior knowledge of the dry weight per ha yielded from a specific crop. Some crop residue statistics are provided by the Greenhouse Gas Inventory Reference Manual, pages 4.69 - 4.73 (IPCC, 1995). The following ratios for residue/crop product are given: wheat 1.3, barley 1.2, maize 1, oats 1.3 and rye 1.6.

6 RELEVANT ACTIVITY STATISTICS

The activity statistics is the amount (dry weight) of waste/residue combusted.

7 POINT SOURCE CRITERIA

8 EMISSION FACTORS, QUALITY AND REFERENCES

The emission factor given by Lee and Atkins (1994) is 2.4 mg NH_3 per gram straw (consisting of 80% NH_3 and 20% NH_4).

9 SPECIES PROFILES

This chapter covers emissions of NH_3 and particulate NH_4 only from this source.

10 CURRENT UNCERTAINTY ESTIMATES

11 WEAKEST ASPECT/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

The weakest area in this source is the lack of data on emission factors.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

Spatial disaggregation relies upon a knowledge of the location of crop waste/residue burning. This may be crudely estimated from local country statistics on land-use.

13 TEMPORAL DISAGGREGATION CRITERIA

This relies upon prior knowledge of current agricultural practices, although it is likely that the activity will take place shortly after crop harvesting.

14 ADDITIONAL COMMENTS

Stubble burning of crop residues will also release other gases like NH_4, CO, N_2O and NO_x. IPCC recommends the following procedure. Starting with an estimation of the total amount of biomass burned, total amounts of released carbon and nitrogen are calculated. The emissions of $CH_4$and CO are related to the total mass of carbon released and the emissions of N_2O and NO_x to the total mass of nitrogen released. Details and default values are given in the Greenhouse Gas Inventory Workbook, pages 4.22 - 4.26 (IPCC, 1995).

15 SUPPLEMENTARY DOCUMENTS

16 VERIFICATION PROCEDURES

17 REFERENCES

IPCC, 1995. Guidelines for national greenhouse gas inventories. Volume 1 (Reporting Instructions), Volume 2 (Workbook) and Volume 3 (Reference Manual). OECD, Paris.

Lee, D.S. and Atkins, D.H.F., 1994. Atmospheric ammonia emission from agricultural waste combustion. Geophysical Research Letters 21, 281-284.

18 BIBLIOGRAPHY

19 RELEASE VERSION, DATE AND SOURCE

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Date:	November 1995
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SNAP CODE:	**100401** **100402** **100403** **100404** **100405** **100406** **100407**
SOURCE SUB-SECTOR TITLE:	**ENTERIC FERMENTATION** ***Dairy Cows*** ***Other Cattle*** ***Ovines*** ***Fattening Pigs*** ***Horses*** ***Mules and Asses*** ***Goats***
NOSE CODE:	**110.04.01** **110.04.02** **110.04.03** **110.04.04** **110.04.05** **110.04.06** **110.04.07**
NFR CODE:	**N/A**

1 ACTIVITIES INCLUDED

This chapter deals with the methane emissions from animal husbandry. Two sources of methane emission are distinguished: enteric fermentation of agricultural animals and animal waste management. Ammonia emissions from animal husbandry are considered in chapter B1090.

2 CONTRIBUTION TO TOTAL EMISSIONS

From the global methane emissions about 25% originates from animal husbandry. The remaining emissions arise from rice cultivation, natural gas and oil systems, biomass burning, waste treatment, landfills and from animal husbandry is responsible for approximately 7% of the global methane emissions.

Table 1: Methane emission from animal husbandry in 1990 (units in $Tg=10^9$ kg CH_4)

	Europe	World
enteric fermentation	19.6	80
- cattle	16.2	58.1
- sheep	2.5	7.6
animal waste management	5.9	14
- cattle	3.4	6.1
- swine	1.8	5.3
all methane sources		354

Source: EPA, 1994 (Tables 2-9 and 9-6)

CORINAIR 1990 provide some alternative estimates of European emissions.

Contribution to total emissions of the CORINAIR90 inventory (*28 countries*)

Source-activity	SNAP-code	Contribution to total emission [1%]							
		SO_2	NO_X	NMVOC	CH_4	CO	CO_2	N_2O	NH_3
Enteric fermentation	100400	-	-	-	20.5	-	-	-	0.5

0 = emissions are reported, but the exact value is below the rounding limit (0.1 per cent)
- = no emissions are reported

3 GENERAL

3.1 Description

Enteric fermentation

Methane is produced in herbivores as by-product of enteric fermentation, a digestion process by which carbohydrates are broken down by micro-organisms into simple molecules for absorption in the bloodstream. Both ruminant animals (like cattle and sheep) and some non-ruminants like pigs produce methane. The amount of released methane depends on the type, age and weight on the animal, the quality and quantity of the feed and the energy expenditure of the animal.

Animal waste management

Methane is produced from the decomposition of organic components in animal waste. The amount of released methane depends on the quantity of waste produced and the portion of the waste that decomposes anaerobically. When the animal waste is store or treated as a liquid (as in lagoons and pits) it tends to decompose anaerobically and methane can be produced. When the waste is handled as a solid (as in stacked piles) or when it is deposited on pastures, it tends to decompose aerobically and little or no methane is produced.

3.2 Controls

Enteric fermentation

Although the quality of the feed influences the methane emission, in practice it is difficult to change the diet. Increasing milk production per dairy cow means more feed intake per animal, but the amount of feed necessary for maintenance of the dairy cow remains the same. The result is a decreasing methane emission per kg of milk produced.

Animal waste management
There are tow strategies to decrease the methane emissions from animal wastes.

First by preventing the creation of methane by frequently removing settled sludge and solid material from the manure storage. This results in a low number of methane producing bacteria in the storage.

The second method to decrease the methane emission is by creating favourable conditions for the methane producing bacteria in the manure storage or by building a biogas plant. The produced biogas has to be collected and can be used for different purposes (heating, producing electricity). There is very little emission of methane to the atmosphere.

4 SIMPLER METHODOLOGY

The simpler approach for estimating methane emission from animal husbandry is to use an average emission factor per animal for each class of animal and to multiply this factor with the number of animals counted in the annual agricultural census. For enteric fermentation and for animal waste management Table 2 presents the recommended IPCC methane emission factors for the different classes of animals.

5 DETAILED METHODOLOGY

With the simpler methodology default methane emission factors are used. The detailed methodology makes use of country specific information on all the parameters involved like feed intake of the animals, animal waste management systems, emission factors derived from measurements, etc. Also more sub-animal categories can be used than mentioned in Table 2. Once emissions have been calculated at whatever is determined by the national experts to be the most appropriate level of detail, results should also be aggregated up to the minimum standard level of information as given in Table 2. This will allow for comparability of results among all participating countries. The data and assumptions used for finer levels of detail should also be reported to ensure transparency and replicability of results among all participating countries. The data and assumptions used for finer levels of detail should also be reported to ensure transparency and replicability of methods.

6 RELEVANT ACTIVITY STATISTICS

For the simpler methodology, data is required on animal numbers for each of the categories listed in Table 2. The annual agricultural census can supply these data. Otherwise the statistical information from Eurostat can be used or the FAO Production Yearbook.

For the detailed methodology, the data is required on animal numbers. Beside information is needed for all the parameters mentioned in section 5.

7 POINT SOURCE CRITERIA

Emission from this sub-sector should be considered as area sources.

8 EMISSION FACTORS, QUALITY AND REFERENCES

The emission factors are presented in Table 2. Appropriate factors should be selected and inserted into blank Table 3. The new table allows calculation of animal class emission factors which are combined with animal numbers to provide total methane emissions for a country.

Table 2: Methane emission factors for simpler methodology Annually averaged emission in kg CH_4 per animal, as counted in the annual agricultural census

SNAP Code	**Description**	**enteric fermentation**		**manure management**			
		west Europe	**east Europe**	**west Europe**		**east Europe**	
				cool[1]	**temperate**[2]	**cool**[1]	**temperate**[2]
100401	dairy cows	100	81	14	44	6	19
400402	other cattle (young cattle, beef cattle and suckling cows)	48	56	6	20	4	13
100403	pigs (fattening pigs, sows and piglets)	1.5	1.5	3	10	4	7
100404	sheep (adults and lambs)	8	8	0.19	0.28	0.19	0.28
100405	goats (adults and kids)	5	5	0.12	0.18	0.12	0.18
100406	horses	18	18	1.39	2.08	1.39	2.08
100407	mules and asses	10	10	0.76	1.14	0.76	1.14
100408	poultry (chickens, ducks and turkeys)	not estimated		0.078	0.117	0.078	0.117

[1] cool climate: annual average temperature less than 15E C
[2] temperature climate: annual average temperature between 15E C

Source: IPCC, 1995

Table 3: Total methane emission based on methane emission factors and animal class numbers Emission factor in kg CH_4 per animal, as counted in the annual agricultural census

SNAP Code	**description**	**methane emission factors**			**number of animal**	**total methane emission C * D**
		enteric fermentation	**manure management**	**total A + B**		
		A	**B**	**C**	**D**	**E**
100401	dairy cows					
400402	other cattle (young cattle, beef cattle and suckling cows)					
100403	pigs (fattening pigs, sows and piglets)					
100404	sheep (adults and lambs)					
100405	goats (adults and kids)					
100406	horses					
100407	mules and asses					
100408	poultry (chickens, ducks and turkeys)					
	TOTAL					

9 SPECIES PROFILES

10 CURRENT UNCERTAINTY ESTIMATES

Uncertainties in methane emission factors are in the magnitude of 30%.

Uncertainties in animal numbers per class of animals are in the magnitude of 10%.

11 WEAKEST ASPECT/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

The simpler methodology suffices with the methane to the appropriate territorial unit on the base of animal numbers.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

National total emission should be disaggregated to the appropriate territorial unit on the base of animal numbers.

13 TEMPORAL DISAGGREGATION CRITERIA

The simpler methodology suffices with the methane emissions estimate without temporal disaggregation.

The detailed methodology should provide temporal disaggregation if data are available.

14 ADDITIONAL COMMENTS

15 SUPPLEMENTARY DOCUMENTS

No supplementary documents are needed to calculate national methane emissions, as outlined for the simpler methodology. The scientific basis of the emission factors is described in detail in IPCC (1995).

16 VERIFICATION PROCEDURES

17 REFERENCES

EPA, 1994. International anthropogenic methane emissions: estimates for 1990. EPA 239-R-93-010. US Environmental Protection Agency, Washington, D. C., US.

IPCC, 1995. Guidelines for national greenhouse gas inventories. Volume 1 (Reporting Instructions), Volume 2 (Workbook) and Volume 3 (Reference Manual). OECD, Paris.

Johnson, K.A. and D.E. Johnson, 1995. Methane emissions from cattle. J. Anim. Sci. 73, 2483-2492.

Moss, A.R., D.I. Givens, P.C. Garnsworthy, 1994. The effect of alkali treatment of cereal straws on digestibility and methane production by sheep. Animal Feed Science and Technology 49, 245-259.

Steed, J. and A.G. Hashimoto, 1994. Methane emissions from typical manure management systems. Bioresource Technology 50, 123-130.

Zeeman, G., 1994. Methane production/emission in storages for animal manure. Fertilizer Research 37, 207-211.

18 BIBLIOGRAPHY

IPCC, 1995. Guidelines for national greenhouse gas inventories. Volume 1 (Reporting Instructions), Volume 2 (Workbook) and Volume 3 (Reference Manual). OECD, Paris

19 RELEASE VERSION, DATE AND SOURCE

Version:	2.1
Date:	November 1995
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SOURCE ACTIVITY TITLE: ENTERIC FERMENTATION

ACTIVITY	**SNAP CODE**	**NOSE CODE**	**NFR CODE**
Laying Hens	**100408**	**110.04.08**	**-**
Broilers	**100409**	**110.04.09**	**-**
Other Poultry (Ducks, Geese, etc.)	**100410**	**110.04.10**	**-**
Fur Animals	**100411**	**110.04.11**	**-**
Sows	**100412**	**110.04.12**	**-**
Camels	**100413**	**110.04.13**	**-**
Buffalo	**100414**	**110.04.14**	**-**
Other	**100415**	**110.04.15**	**-**

A specific methodology for these activities has not been prepared because the contribution to total national emissions is thought to be currently insignificant, i.e. less than 1% of national emissions of any pollutant.

If you have information contrary to this please contact the expert panel leaders.

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SNAP CODES:	**100501**	**100506**
	100502	**100507**
	100503	**100508**
	100504	**100509**
	100505	**100510**

SOURCE ACTIVITY TITLES: **MANURE MANAGEMENT REGARDING ORGANIC COMPOUNDS**

Dairy cows	***Horses***
Other cattle	***Laying hens***
Fattening pigs	***Broilers***
Sows	***Other poultry***
Ovines	***Fur animals***

NOSE CODE:	**110.05.01**	**110.05.06**
	110.05.02	**110.05.07**
	110.05.03	**110.05.08**
	110.05.04	**110.05.09**
	110.05.05	**110.05.10**

NFR CODE:	**4B1a**	**4B5**
	4B1b	**4B6**
	4B2	**4B7**
	4B3	**4B8**
	4B4	**4B9**
		4B13

1 ACTIVITIES INCLUDED

VOCs comprise both methane and non-methane volatile organic compounds (nmVOCs). nmVOCs are defined as “all those artificial organic compounds different from methane which can produce photochemical oxidants by reaction with nitrogen oxides in the presence of sunlight”.

Methane emissions from enteric fermentation and animal waste management are considered in SNAP code 100400; emissions from unfertilised agricultural land and land fertilised with N-containing fertiliser are considered in SNAP codes 100200 and 100100 respectively.

This chapter considers the emission of non-methane volatile organic compounds (nmVOCs) from the excreta of agricultural animals deposited in buildings and collected as either liquid slurry or solid manure. This includes emissions from animal excreta at all stages: animal housing, manure storage and from land spreading of manures. Emissions from excreta deposited in fields by grazing animals should be dealt with under SNAP codes 100100 (Cultures with fertilisers) and 100200 (Cultures without fertilisers) in this Guidebook. However, no nmVOC emission factors are available there.

2 CONTRIBUTIONS TO TOTAL EMISSIONS

2.1 Methane

Each microbial fermentation of digestible organic matter under anaerobic conditions results in methane formation. In agriculture, these conditions are met in the animal digestive systems and during the storage of animal wastes. Overall, agriculture's contribution adds up to nearly 50 % of the total (EU15 for 1999, EEA 2001). Animal husbandry is the major agricultural source (96 % of the agriculture total). As mentioned above, these emissions are not object of chapter 100500.

2.2 Non-methane volatile organic compounds

In the CORINAIR90 inventory (29 countries), emissions of nmVOCs from agriculture account for only 2% of total nmVOC emissions; the greatest proportion (98%) is emitted by other activities.

The contribution to total nmVOC emissions from cultures and from stubble burning is very low (0.2% for both) and nil from enteric fermentation. Emission estimates for manure management account for 1.6 % (with 1.4 % for pigs) but even this value is not of great significance.

The estimates of the nmVOC emission for each European Country show a wide variations in the percentage of VOC emissions attributed to agriculture, ranging from 0% to 39,8% (Ireland).

3 GENERAL

3.1 Description

3.1.1 Methane

Methane is produced from the decomposition of organic components in animal waste. The amount of released methane depends on the quantity of waste produced and the portion of the waste that decomposes anaerobically. When the animal waste is store or treated as a liquid (as in lagoons and pits) it tends to decompose anaerobically and methane can be produced. When the waste is handled as a solid (as in stacked piles) or when it is deposited on pastures, it tends to decompose aerobically and little or no methane is produced.

3.1.2 Non-methane volatile organic compounds

A list of the principal nmVOCs, from the main emission sources, and a classification of the VOCs according to their importance, is included in the protocol regarding the fight against emissions of volatile organic compounds and their transnational flows, drafted in Geneva on 18/11/1991 during the congress on Long-Distance Transnational Atmospheric Pollution of 1979.

The protocol classifies nmVOCs into three groups, according to their importance in the formation of ozone episodes. Both the global quantity emitted and the VOCs reactivity with OH-radicals are considered.

There is very little information about nmVOCs emissions from animal manure which is required to make quantitative estimates and identification of emission factors. However, because nmVOCs are responsible for odour emissions and nuisance, both the compounds in the air of livestock buildings and in manure and the techniques to measure the odour emissions have been investigated.

An exhaustive list of organic compounds identified in livestock buildings was compiled by O'Neill and Phillips (1992) on the basis of a literature review. The compounds most frequently reported in these investigations, which are heavily biased towards piggeries, are *p*-cresol, volatile fatty acids and phenol. Concentrations of these compounds in the atmosphere display wide variations; e.g. the concentration of *p*-cresol varies from $4.6 \cdot 10^{-6}$ to 0.04 mg m^{-3} and of phenol from $2.5 \cdot 10^{-6}$ to 0.001 mg m^{-3}.

An attempt to estimate quantitative gas emissions from pig housing in former West Germany has been done by Hartung and Phillips (1994) based on concentration data for 23 trace gases measured in piggeries. Fatty acids (acetic, propionic, *i*- and *n*-butyric, *i*- and *n*-valeric, *i*- and *n*-hexanoic, heptanoic, octanoic and pelargonic acids), phenols and indoles (phenol, *p*-cresol, indole, skatole), methylamines and other gases as acetone were measured, assuming an average ventilation rate of 150 m^3 LU^{-1} h^{-1}.

3.2 Controls

3.2.1 Methane

There are two strategies to decrease the methane emissions from animal wastes: Firstly, the formation of methane is reduced by frequently removing settled sludge and solid material from the manure storage. This results in a low density of methane producing bacteria in the storage. Secondly, methane emissions increase by creating favourable conditions for the methane producing bacteria in a biogas plant. The produced biogas has to be collected and can be used for different purposes (heating, producing electricity). There is very little emission of methane to the atmosphere.

3.2.2 Non-methane volatile organic compounds

Techniques which reduce ammonia and odour emissions can also be considered effective in reducing the emission of nmVOCs from animal manure. Hence, in order to reduce emissions from livestock buildings, techniques mentioned for ammonia (SNAP code 100900) can be applied (e.g. immediate removal of urine from cubicles for cattle, fast removal of slurry for pigs and belt drying of manure inside the poultry houses for laying hens). Other techniques which result in a reduction of the emission of nmVOCs are covering the slurry storage outside the building, and collecting and burning biogas which is generated is the most effective way. But also systems already described for reducing ammonia emissions from storage such as natural and artificial floating crust and floating mats may give some odour reduction due to reduction of the emission of VOCs (Mannebeck, 1986). Injection of slurry is an effective way to reduce emission of nmVOCs during spreading. Odour emission reduction by these methods has been measured, but these data are not directly applicable to nmVOCs.

4 SIMPLER METHODOLOGY

Compared to the total emission of nmVOCs from other sectors the contribution from agriculture (animal manure) seems to be negligible. At present, data of nmVOC emission from animal manure (livestock buildings, storage and spreading) do not allow to estimate any average emission factors for these compounds. Experimental work on direct measurements to estimate nmVOC emission factors is needed.

5 DETAILED METHODOLOGY

6 RELEVANT ACTIVITY STATISTICS

7 POINT SOURCE CRITERIA

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

9 SPECIES PROFILES

10 UNCERTAINTY ESTIMATES

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

Lack of measurements of VOC emissions from manure management is a major weakness.

12 SPATIAL DISSAGGREGATION CRITERIA FOR AREA SOURCES

13 TEMPORAL DISAGGREGATION CRITERIA

14 ADDITIONAL COMMENTS

15 SUPPLEMENTARY DOCUMENTS

16 VERIFICATION PROCEDURES

17 REFERENCES

EEA, 2001. Annual European Community Greenhouse Gas Inventory 1990-1999. Submission to the Secretariate of the UNFCCC. Technical Report No. 60. EEA, Copenhagen.

Hartung J., Phillips V.R., 1994. Control of gaseous emissions from livestock buildings and manure stores. J. Agric. Eng. Res. 57, 173-189.

Mannebeck H., 1986. Covering manure storing tanks to control odour. In: Odour prevention and control of organic sludge and livestock farming. Elsevier, London., pp. 188-193.

O'Neill D.H., Phillips V.R., 1992. A review of the control of odour nuisance from livestock buildings: Part 3, Properties of the odorous substances which have been identified in livestock wastes or in the air around them. J. Agric. Eng. Res. 53, 23-50.

18 BIBLIOGRAPHY

19 RELEASE VERSION, DATE AND SOURCE

Version:	1.2
Date:	July 2002
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Contribution from:	This chapter originally formed a part of chapter 1050 "Manure Management Regarding Organic Compounds" including both carbon and nitrogen compounds, from which it was extracted.
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SOURCE ACTIVITY TITLE: MANURE MANAGEMENT REGARDING ORGANIC COMPOUNDS

ACTIVITY	**SNAP CODE**	**NOSE CODE**	**NFR CODE**
Goats	**100511**	**110.05.11**	**4 B 4**
Mules and Asses	**100512**	**110.05.12**	**4 B 7**
Camels	**100513**	**110.05.13**	**4 B 5**
Buffalo	**100514**	**110.05.14**	**4 B 2**
Other	**100515**	**110.05.15**	**4 B 13**

A specific methodology for these activities has not been prepared because the contribution to total national emissions is thought to be currently insignificant, i.e. less than 1% of national emissions of any pollutant.

If you have information contrary to this please contact the expert panel leaders.

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SNAP CODE: **100600**

SOURCE ACTIVITY TITLE: **USE OF PESTICIDES (AGRICULTURE)**

NOSE CODE: **110.06.01**

NFR CODE: **4 G**

1 ACTIVITIES INCLUDED

This chapter considers the emission of a selection of pesticides to air. The emission is estimated from the agricultural use of pesticides and an emission factor. Other emission sources (e.g. the manufacturing of pesticides or emission of imported products) are considered to be negligible compared to emissions caused by the agricultural use of pesticides.

The pesticides included are Aldrin, Chlordane, DDT, Dieldrin, Endrin, Heptachloor, Hexachlorobenzene, Mirex, Toxaphene, Pentachlorophenol and Lindane. These pesticides have been selected for the baseyear 1990. In the future other pesticides may also be included.

2 CONTRIBUTION TO TOTAL EMISSIONS

It is estimated that > 99% of the total pesticide emissions in Europe originate from the agricultural use of pesticides. The remainder is contributed by industrial sources, and emission of imported crops, and is not included in this chapter. A Dutch study estimated that, on average, 25% of all pesticide used emits to the air.

3 GENERAL

3.1 Description

Pesticide emissions from the agricultural use of pesticides are possibly influenced by:

- The way in which a pesticide is applied;
- Whether or not application takes place in closed spaces (greenhouses);
- The vapour pressure of the pesticide involved;
- The additions to the pesticides, that are used to obtain better spray results;
- The meteorological conditions during application;
- The height of the crop.

In order to calculate pesticide emissions precisely, it would be necessary to have quantitative data on all the factors noted above. In practice these data are not available, and even data on the way in which pesticides are applied are scarce and mostly unreliable. Therefore, the emission factors that are given in Table 8.1 can be considered as first estimates, assuming that application takes place under normal field conditions (ie. no soil injection), with a standard meteorology.

3.2 Controls

There is very little known about methods that may reduce pesticide emissions. Although it is clear that injection into the soil is very effective, it is only suitable in limited circumstances. In addition, there might be some way of reducing the emissions when effective additives can be found. Mineral oil, for instance, is used as an additive to get a better coverage of the crop, but it (or other compounds) may also have an effect on air emissions. In practise though there are no additives used to reduce air emissions.

4 SIMPLER METHODOLOGY

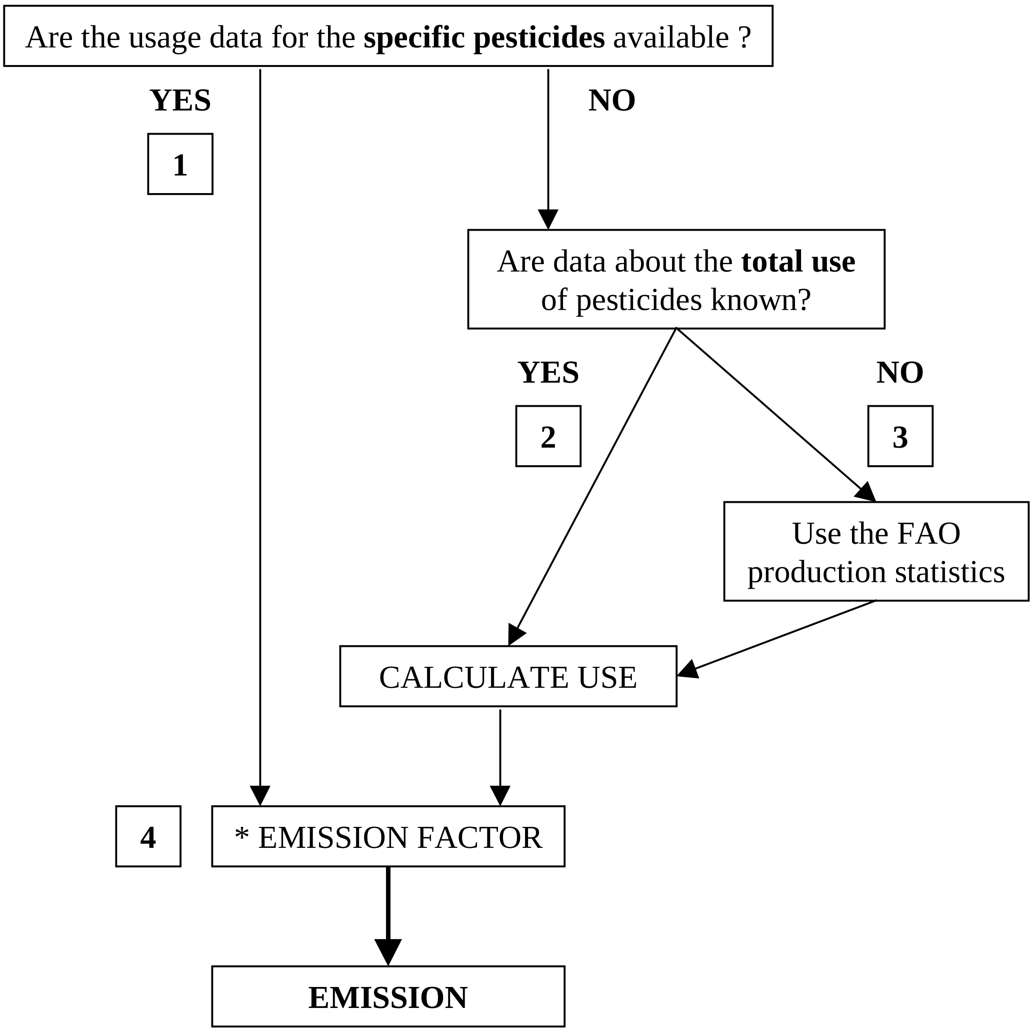
The emission of pesticides during application in the field is by far the most important way in which pesticides emit to the air. There are no direct pesticide emission data available for the different countries. Therefore the emission is estimated from the use of the pesticides and an emission factor as:

Emission = use * emission factor

Both emission and pesticide use are given in tonne/yr. Relevant activity statistics and emission factors are given in sections 6 and 8. Methods for estimating the use of pesticides are described below.

Methods for estimating the use of pesticides
The use of pesticides can be estimated using three starting points, depending upon which data are available. It is not necessary to follow the same procedure for different pesticides for one specific country when the required data are not available. Data do seem to be more comparable using the same method to make estimates for the emission; however, the uncertainties of all methods described are quite big (see section 10). Figure 4.1 (over) gives a schematic overview of these three different methods.

Figure 4.1: Flow scheme for the calculation/estimation of the emission of pesticides



The three methods to estimate the emission of pesticides are described below, starting from the most reliable data.

1 **Consumption is known for individual pesticides**
The most reliable data are obtained when pesticide consumption is known.

2 **Totals of pesticide consumption are known**
When there are no direct figures on pesticide consumption for an individual pesticide, the consumption figures are derived from the total pesticide consumption figures. This is done in three steps:

a Take the OECD data on total pesticide consumption figures. These data are available for most countries in Europe, split into insecticides and herbicides (see Table 6.1).
b Take the relative use of the specific pesticide from Table 6.2.
c Calculate the use of a specific pesticide, assuming that the relative use of the pesticide mentioned is applicable for your country.

Example: What is the use of Lindane in Austria?
This can be estimated in the following way:
Lindane is an insecticide and the total use of insecticides in Austria equals 500 t/yr (Table 6.1). The use of Lindane equals 5% of total insecticide use in Austria (Table 6.2); so the Lindane use in Austria equals: *500 t/yr * 5 % = 25 t/yr*

Note: It is important to realise that this method is only a tool with limitations to calculate the use and emission of the pesticides, because of lack of data. The limitation of this methodology can easily be illustrated by the fact that there is a significant shift in the relative contribution of lindane to the total use of insecticides from year to year.

3 No consumption data are available.
When no pesticide consumption data are available, it is possible to make estimates based on production statistics and comparison with other countries:

a Identify the main crops where the pesticides of interest (ie. those listed in table 8.1) are being used (e.g. cereals, maize).
b Take the total production of the selected crop(s) from FAO data.
c Take the total crop production for a neighbouring or economically comparable country, where pesticide use is known or calculated, from the FAO data.
d Calculate the pesticide use, assuming it is proportional to the amount of crop produced.

Example: What is the use of Lindane in Czechoslovakia?
Lindane is used mainly in cereals. FAO production statistics for cereals in Czechoslovakia equals 12.626.000 Mt. In Austria (as a neighbouring country) 5.290.000 Mt of cereals was produced, and the use of Lindane equalled 25 t/yr. So the Lindane use in Czechoslovakia is calculated to be: *(12.626.000/5.290.000) * 25 = 60 t/yr*

4 Total emission
The total emission of a specific pesticide can now be calculated by multiplying the total use (calculated as above) and the emission factor (see Section 8).

5 DETAILED METHODOLOGY

Not available.

6 RELEVANT ACTIVITY STATISTICS

Table 6.1: OECD data on the use of pesticides in 1990

Country	**Insecticides Ton/yr**	**Herbicides ton/yr**	**Available baseyear**
Austria	500	3053	1986
Belgium	1313	5307	1989
Canada	2262	26414	1990
Denmark	146	1426	1991
Finland	69	1375	1991
France	7096	33713	1991
Germany	1525	16957	1990
Greece	2844	3031	1989
Hungary	2806	9622	1989
Iceland	1	2	1983
Ireland	162	1097	1991
Italy	10744	10566	1989
Netherlands	745	3330	1989
Norway	19	965	1990
Poland	1065	11875	1989
Portugal	2700	5000	1989
Spain	52754	20342	1989
Turkey	10412	7191	1991
USA	79450	224730	1991
USSR	1298	12450	1985
Sweden	19	1054	1991
Switzerland	153	925	1989

Data on the relative use of pesticides are given in Table 6.2. No data are available on the use of Toxaphene and Chlordane. Just as for the pesticides Drins, Heptachlor, DDT and Mirex use of Toxaphene and Chlordane is forbidden in Europe and America (relative use=0).

Table 6.2: Relative use of pesticides (in % of total use of insecticides or fungicides per country) (Berdowski et al., 1997)

Country	Lindane	PCP*	HCB*	Drins*	DDT	heptachlor	Mirex
Austria	5.0	41	<0.1	0	0	0	0
Belgium	2.7	2.2	<0.1	0	0	0	0
Canada	3	0.5	*	0	0	0	0
Denmark	3.4	0.5	<0.1	0	0	0	0
Finland	23	10	<0.1	0	0	0	0
France	7.0	0	<0.1	0	0	0	0
Greece	0.9	12	<0.1	0	0	0	0
Hungary	3.5	11	0.1	0	0	0	0
Iceland	5.0	0	<0.1	0	0	0	0
Ireland	3.1	11	<0.1	0	0	0	0
Italy	0.9	1.2	<0.1	0	0	0	0
Netherlands	4.0	0.5	-	0	0	0	0
Norway	32	31	<0.1	0	0	0	0
Poland	0.2	0	<0.1	0	0	0	0
Portugal	0.2	6.1	<0.1	0	0	0	0
Spain	0.2	0	<0.1	0	0	0	0
Turkey	1	12	<0.1	0	0	0	0
USA	3	0.5	<0.1	0	0	0	0
USSR	75	nd	<0.1	0	0	0	0
Sweden	22	0	<0.1	0	0	0	0
Switzerland	0.7	8.4	<0.1	0	0	0	0
Germany	4.6	0	-	0	0	0	0

* PCP = pentachlorophenol; HCB = hexachlorobenzene; Drins = aldrin + dieldrin + endrin
nd = no data

The percentages mentioned in Table 6.2 originate from The European Emission Inventory of Heavy Metals and Persistent Organic Pollutants. Percentages for USA, Turkey and Canada are estimated, based on neighbouring countries or on countries lying on the same longitude. No data are available for toxaphene and for USSR for Pentachlorophenol.

7 POINT SOURCE CRITERIA

Not applicable.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

The emission factors are derived from the vapour pressure of the pesticides. The vapour pressure is until now the most convenient way to begin to estimate the emission. Other estimates may take into account Henry coefficient or other parameters but there are not enough data available to make a more reliable estimate of the emission factors.

The emission factors are derived from the vapour pressure according to the next schedule:

Vapour pressure	**mPa**	**Emission Factor**
very high	> 10	0.95
high	1 - 10	0.50
AVERAGE	0.1 - 1	0.15
low	0.01 - 0.1	0.05
very low	< 0.01	0.01

Table 8.1 gives the estimated emission factors for the pesticides considered in this chapter.

Table 8.1: Pesticides and estimated emission factors

Pesticide	**Type**	**Emission Factor**
Aldrin	Insecticide	0.50
Chlordane	Insecticide	0.95
DDT	Insecticide	0.05
Dieldrin	Insecticide	0.15
Endrin	Insecticide	0.05
Heptachloor	Insecticide	0.95
HCB (Hexachlorobenzene)	Fungicide*	0.50
Mirex	Insecticide	0.15
Toxaphene	Insecticide	0.15
PCP (Pentachlorophenol)	Fungicide*	0.95
Lindane	Insecticide	0.50

* PCP and HCB are not only used in agriculture. The emission factors only apply to the agricultural use.

Comparing these factors with former emission factors made for OSPARCOM-HELCOM-UNECE (TNO-Report TNO-MEP-R 95/247) the values have changed. Explanation is the more detailed classification. In the former study three different classes were distinguished; this methodology determines five classes.

When more recent data from Table 6.1 or 6.2 are available, other countries might have calculated their emissions using the ‘old data’. Recalculation might be of interest.

9 SPECIES PROFILES

Not applicable

10, 11 CURRENT UNCERTAINTY ESTIMATES AND PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

Uncertainties in pesticide emissions are in the magnitude of a factor of 2 - 5. Uncertainty is introduced by poor emission factors. There are reliable emission factors for only for a few compounds (about 15). The emission factors for the other compounds (about 800 different compounds are allowed in the EEC) are derived by extrapolation or from few measurements.

The other difficulty is that data on the use of pesticides are scarce and unreliable for most countries. Though these data are sometimes available, they are not always available for research groups. Making these figures public is an easy way to get a major improvement in the data.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

Considering the potential for pesticides to have local effects on ecology, emission estimates should be disaggregated on the basis of land use data as much as possible.

13 TEMPORAL DISSAGGREGATION CRITERIA

The methodology does not give emissions with a temporal dissaggregation, although the use (and emission) of pesticides takes place during the growing season.

14 ADDITIONAL COMMENTS

No additional comments.

15 SUPPLEMENTARY DOCUMENTS

- FAO production statistics
- OECD pesticide data

16 VERIFICATION PROCEDURES

-

17 REFERENCES

Berdowski, J.J.M.; J. Baas; J.P.J. Bloos; A.J.H. Visschedijk, P.Y.J. Zandveld (1997). The European Emission Inventory of Heavy Metals and Persistant Organic Pollutants for 1990. UBA/TNO Forschungsbericht 104 02 672/03.

FAO Yearbook Production, vol 46 (1992).

MJPG-Emissie-evaluatie (1995) Achtergronddocument Commissie van deskundigen Emissie-Evaluatie MJP-G, IKC, Ede.

OECD Environmental data, Compendium (1993).

Worthing, C.R.; Hance, R.J (1991) The pesticide manual (a world compendium), 9th Edition, The British Crop Protection Council, Farnham.

18 BIBLIOGRAPHY

-

19 RELEASE VERSION, DATE AND SOURCE

Version: 1.2

Date: May 2000

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20 POINT OF ENQUIRY

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SNAP CODES :

10 09 01
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10 09 11
10 09 12
10 09 13
10 09 14
10 09 15

SOURCE ACTIVITY TITLE :

MANURE MANAGEMENT REGARDING NITROGEN COMPOUNDS

Dairy cows
Other cattle
Fattening pigs
Sows
Sheep
Horses
Laying hens
Broilers
Other poultry
Fur animals
Goats
Mules and asses
Camels
Buffalo
Any other animals

NOSE CODES :

110.09.01
110.09.02
110.09.03
110.09.04
110.09.05
110.09.06
110.09.07
110.09.08
110.09.09
110.09.10
110.09.11
110.09.12
110.09.13
110.09.14
110.09.15

NFR CODES :

4B1a
4B1b
4B2
4B3
4B4
4B5
4B6
4B7
4B8
4B9
4B13

1 ACTIVITIES INCLUDED

This chapter considers the emissions of ammonia (NH_3) and nitrous oxide (N_2O) from the excreta of agricultural animals deposited in buildings and collected as either liquid slurry or solid manure. This includes emissions from animal excreta at all stages: animal housing, manure storage and from land spreading of manures. Excreta deposited in fields by grazing animals are dealt with under SNAP codes 100100 (Cultures with fertilisers) and 100200 (Cultures without fertilisers) in this Guidebook. However, the calculation procedure is part of this chapter.

2 CONTRIBUTIONS TO TOTAL EMISSIONS

2.1 Ammonia

Approximately 80 - 90 % of the total ammonia emissions in Europe originates from agricultural practices, the remainder from industrial sources, households, pet animals and natural ecosystems. Only emissions from agricultural sources are included in this chapter.

Ammonia emissions from animal excreta contribute over 80 % and those from application of fertilisers less than 20 % to the total ammonia emissions of agricultural origin in Europe (The Netherlands: 1998: 92 and 8 %, Koch et al., 2001, see also table 2.1; Germany: 1996: 84 and 16 %, Döhler et al., 2002; Switzerland 1995: 89 and 11 %, Eidgenössische Forschungsanstalt, 1997; Spain 1996: 78 and 22 %, Spanish Ministry of Agriculture, 2001; UK 1997: 91 and 9 %, Pain et al., 1998). There is, however, a wide variation from country to country and within the main animal categories, cattle, sheep, pigs and poultry. This variation from country to country is partly explained by the different distribution of animals over the main categories, their respective nitrogen excretion and the emission factors reflecting differences in agricultural practices, and housing systems and climate.

Table 2.1 Percentage contributions of ammonia emissions of agricultural origin (Animal excreta and fertiliser application only)

	European average[1]	Range for individual countries[2]	The Netherlands[3]	Germany[4]	Spain[5]	United Kingdom[6]
Year	1989	1989	1990	1996	1996	1996
Animal excreta	83 %	68 – 95 %	95 %	84 %	78 %	91 %
- cattle	55 %	21 – 83 %	54 %	55 %	35 %	55 %
- sheep and goats	5 %	0 – 35 %	2 %	0.4 %	9 %	6 %
- pigs	15 %	0 – 41 %	31 %	21 %	25 %	11 %
- poultry	6 %	0 – 10 %	8 %	6 %	7 %	19 %
Fertiliser application	17 %	5 – 32 %	5 %	16 %	21 %	9 %

[1,2] Asman, 1992
[3] Van Der Hoek, 1994
[4] Döhler et al., 2002
[5] Spanish Ministry of Agriculture, 2001
[6] Pain et al., 1998

2.2 Nitrous Oxide

IPCC estimates the global present-day emission of N2O-N at 14.7 (10 - 17) Tg a-1 N2O-N, of which 5.7 (3.7 - 7.7) Tg a-1 N2O-N is considered due to human activities (IPCC, 1995). Anthropogenic emissions result mainly from agricultural activities. Emissions from agricultural soils and livestock housing amount to 3.9 (2 - 5.8) Tg a-1 N2O-N.

Combustion of fossil fuels, in particular for transportation, is another important source of N_2O, as well as biomass burning and industrial production of, for instance, nitric acid for synthetic fertilisers.

Table 2.2 Percentage contributions of nitrous oxide emissions of agricultural origin [1]

	Emission rates for EU 15 in Gg a^{-1}	Relative contribution EU 15 in %
Year	1995	1995
Mineral arable soils	190	46
Grassland soils	100	24
Farmed organic soils	38	9
Animal houses	23	6
Manure storage	9	2
Grazing	53	13
Total	413	100

[1] Freibauer & Kaltschmitt, 2001

In accordance with the revised IPCC Guidelines for National Greenhouse Gas Inventories (IPCC/OECD/IEA 1997), this Guidebook considers only animal manure management systems and soil emissions (both direct and indirect) as agricultural sources of N_2O. It is recognized that emissions from animal production are considerable on a global scale. Animal manure management systems alone account for about one-third of the agricultural emissions (Mosier et al., 1998).

3 GENERAL

3.1 Description

3.1.1 Ammonia

Ammonia emissions from animal husbandry occur during both the housing and grazing periods. This section deals primarily with emissions from the housed component of animal production. However, the results obtained for the grazing component are calculated in this chapter and are supplied for use in SNAP Code 100100.

In the case of housed animals, emissions may be divided into those occurring directly from animal houses and those associated with the subsequent storage and land spreading of animal manures.

Ammonia emissions from livestock depend on many factors including:

- the nitrogen content of the feed,
- the species, age and performance (e.g. milk yield, weight gain) of the animal,
- the conversion of nitrogen in feed to nitrogen in meat, milk and eggs and, hence, the amount of nitrogen in the animal excreta,
- the housing system of the animal, including storage of the manures inside the building,
- the storage system of the manure outside the building: open or covered slurry tank, loose or packed pile of solid manure,
- climatic conditions in the building and the storage system, e.g. temperature,
- the proportion of time spent by animals indoors and outside, e.g. at pasture or in yards.

Ammonia emissions from animal manures during and after spreading depend on:

- spreading techniques and the surface exposed of the respective manure,
- properties of the animal wastes including viscosity, ammoniacal nitrogen content and pH,
- soil properties such as pH, cation exchange capacity, calcium content, water content, buffer capacity and porosity,
- meteorological conditions including precipitation, temperature, humidity and wind-speed,
- the method and rate of application of animal manures, including, for arable land, the time between application and incorporation,
- the height and density of the crop or grassland.

In order to calculate ammonia emissions precisely, it is necessary to have quantitative data on all the factors noted above. In practice, results are summarized to provide 'average' emission factors per animal for each stage of emission for the main livestock classes and management types. Total ammonia emissions are then scaled by the numbers of animals in each country.

3.1.2 Nitrous Oxide

In 1995-1996 an IPCC/OECD/IEA working group developed a revised methodology for estimating N_2O emissions from agriculture (Mosier et al., 1998). The methodology was approved of by the Intergovernmental Panel on Climate Change (IPCC) and has been included in the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC/OECD/IEA, 1997).

The IPCC Guidelines for National Greenhouse Gas Inventories provide default emission factors for direct and indirect soil emissions and different types of animal waste management systems (IPCC/OECD/IEA, 1997). The method aims at assessing the full nitrogen cycle, taking into account N_2O formation in agricultural soils (as a result of N inputs or soil cultivation), animal waste management systems, as well as indirect formation of N_2O after agricultural N is emitted as NH_3 or NO_x or leaches from the agricultural system to groundwater and surface waters.

Nitrous oxide emissions from agricultural activities are known to be regulated by many parameters. Specific characteristics of soils, crops, types of fertiliser, and climate largely influence biogenic N_2O formation in soils. As a result, the observed N_2O fluxes from agricultural fields show large spatial and regional variation. However, these factors were not included in the IPCC methodology for estimating direct N_2O emission from agricultural soils on a national scale, because the available data do not allow for identification of appropriate emission factors (Bouwman, 1996; Freibauer & Kaltschmitt, 2001). Instead, the IPCC Guidelines provide a methodology to estimate N_2O emissions as a percentage of N that is imported into the system as a result of human activity. The input data needed can all be obtained from FAO databases.

The IPCC Guidelines distinguish between emissions from domestic livestock (IPCC terminology: animal waste management) and agricultural soils. The IPCC source categories differ from the CORINAIR sub-sectors. This paper presents a guideline for estimating emissions for CORINAIR subcodes, using the IPCC Guidelines for National Greenhouse Gas Inventories (Table 3.1).

Nitrous oxide emissions from manure management according to EMEP/CORINAIR definitions include:

- emissions from livestock housing (6 “animal waste management” systems, but excluding grazing animals);
- direct soil emissions due to manure-N inputs when using manure as fertiliser (but excluding grazing animals);
- indirect emissions due to NH_3 and NO_x emissions from animal manure, excluding N excretion by grazing animals;
- indirect emissions due to N-leaching and runoff from animal manure, excluding N excretion by grazing animals.

Table 3.1 Summary of IPCC source categories (IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2: Workbook, 1997) to be reported as CORINAIR sub-sectors for agriculture

CORINAIR SUB-SECTOR (SNAP code)	IPCC N_2O SOURCE (IPCC Workbook Worksheet)
Cultures with/without fertilisers (100100/100200)	- Direct soil emissions due to N-inputs excluding manure (worksheet 4-5, sheet 1, excluding animal waste F_{aw}) - Direct soil emissions due to histosol cultivation (worksheet 4-5, sheet 2) - Direct soil emissions from grazing animals; pasture, range & paddock (worksheet 4-5, sheet 3) - Indirect emissions due to NH_3 and NO_x emissions from synthetic fertiliser use and grazing animals (worksheet 4-5, sheet 4, excluding animal waste used as fertiliser) - Indirect emissions due to N leaching/runoff from synthetic fertiliser use and grazing animals (worksheet 4-5, sheet 5, excluding animal waste used as fertiliser)
Manure Management (100900)	- Manure management: 6 waste management systems (worksheet 4-1, sheet 2, excluding pasture, range & paddock) - Direct soil emissions due to manure N-inputs excluding grazing animals (worksheet 4-5, sheet 1, row for animal waste F_{aw} only) - Indirect emissions due to NH_3 and NO_x emissions from animal waste excluding grazing animals (worksheet 4-5, sheet 4, animal waste used as fertiliser only) - Indirect emissions due to N leaching/runoff from animal waste excluding grazing animals (worksheet 4-5, sheet 5, animal waste used as fertiliser only)

Both IPCC Guidelines and the EMEP/CORINAIR Guidebook give default values for nitrogen excretion by livestock in kg N per animal per year (Table 4.1 in this chapter of the EMEP/ CORINAIR Emission Inventory Guidebook, and Table 4-6 of Volume 2 of the IPCC Guidelines; IPCC/OECD/IEA, 1997). Countries are recommended to use the EMEP/ CORINAIR default values for nitrogen excretion by livestock in a consistent way.

3.1.3 Nitric oxide

Nitric oxide (NO) is primarily produced by nitrification; it should therefore be formed in the surface layers of stored manure. At present, no data are available describing NO emissions from manure management.

3.2 Controls

3.2.1 Ammonia

There are a number of potential methods for reducing ammonia emissions. With any of these methods, it is essential that due care is taken to ensure that any nitrogen conserved is made available as plant fertiliser and does not cause other environmental problems such as nitrate leaching or nitrous oxide emissions.

A wide range of control techniques are available for reducing ammonia emissions, depending on the source type and existing management practices (for details see Tables in Appendix B).

Feeding: Animal feeding strategies can also be used for reducing ammonia emissions. A better adjustment of protein supply in the feed to the protein requirement of the animal results in a lower nitrogen excretion. This approach is most effective with monogastric animals. For ruminants, the issue is complicated by the digestability of carbohydrates in the feed. The achievable reduction of ammonia emission is lower than with modification of the housing systems, but the associated costs are also much lower.

Housing: A reduction of the area polluted with urine and faeces and hence the emitting surface results in decreased emissions. However, means to improve animal welfare are likely to result in larger surface areas per animal and hence increased emission rates. Housing with out-door climate may reduce temperature and thus the vapour pressure of ammonia in excreta. An emission reduction may be obtained for pigs. Technical systems like grooved floors combined with an adequate scraping are likely to reduce emissions from cattle houses. For laying hens, manure drying and manure belts increase evaporation and by drying the excreta reduce the breakdown of uric acid to urea, hence reducing the formation of ammonia.

Slurry and manure treatment systems: Anaerobic digestion of slurry results in an increased share of TAN. However, the treated slurry has a reduced viscosity and thus penetrates the soil surface more easily. Anaerobic digestion is likely to reduce ammonia emissions from spreading slightly. Slurry separation leads to considerably reduced ammonia emissions due to increased penetration rates of the slurry. The emissions from the solid separate are comparatively small. Composting of solid manure increases ammonia emissions during the composting process and storage drastically; overall losses were much greater from composted than from uncomposted manure despite the fact that there are no subsequent losses during spreading (Amon et al., 1998).

Storage: Covering the slurry storage tank outside the building with a tight roof decreases the emission of ammonia by about 80 %. Often cattle slurry generates a floating crust, which is less effective in reducing the emission of ammonia (about 50 % reduction of emission). Other control options also require modified housing conditions. Examples are immediate removal of urine in cubicle houses for cattle, keeping the temperature of stored pig manure in pig housing below 15 °C. These techniques can give 50 % or more emission reduction but they are quite expensive and as yet no legislation has been applied to encourage these approaches, which require careful management to be effective.

Spreading: Emissions from manure and slurry spreading can be reduced efficiently using technical systems which reduce the effective emitting surface and thus the gaseous exchange between slurry and air. Low emission land spreading techniques include bandspreading and injection of slurries and directly ploughing in or harrowing after application to arable land. In several countries legislation already exists for land spreading of animal wastes (The Netherlands: Besluit Gebruik Dierlijke Meststoffen, 1991; England: see Brewer and Davidson, 1999; Germany: Düngeverordnung, 1996; Sweden: see Jakobsson, 1999).

Where applicable, low emission techniques such as injection can give up to 80 % reduction in ammonia emission on grassland, compared to surface spreading of animal manures. However, injection techniques are not suitable for stony or sloping fields, or in all weather conditions.

For arable land, 80 % reduction in ammonia emission is achievable when the wastes are harrowed or ploughed in within 4-6 hours after application of the wastes to the soil.

The vapour pressure of ammonia is significantly influenced by temperature. Hence spreading during cooler seasons or periods leads to reduced emissions. In some countries the Meteorological Service provides estimates of ammonia losses as a function of time of the respective day.

However, any technique that reduces emissions and thus increases nitrogen inputs into soils has the potential to increase nitrate leaching, stimulate N_2O formation etc.

3.2.2 Nitrous Oxide

As described earlier, manure management may lead to N_2O emissions

- from animal manure management systems,
- from agricultural soils due to use of manure as fertiliser and
- indirectly, following NH_3 and NO_x emissions or N leaching and runoff.

Emissions from animal housing (animal manure management systems) could be reduced by shifting towards systems having low emissions of N_2O. Storage of manure at aerobic conditions is known to result in more N_2O formation than anaerobic storage of manure, as reflected in the emission factors. It should be noted, however, that systems with low N_2O emissions may have relatively high emissions of NH_3 and CH_4.

The amount of N_2O formation in agricultural soils following some amount of N input is difficult to reduce. Some studies show that, under specific circumstances, certain types of fertilisers give rise to higher emissions than others. However, it is as yet not possible to formulate general rules for fertiliser use leading to a reduction in N_2O emissions. The use of chemical inhibitors (e.g. nitrification inhibitors) has been shown to decrease N_2O formation for some time. However, it is as yet not known what the side-effects and long-term effects of inhibitors are on agricultural and surrounding natural soils. Inhibitors are therefore not recommended.

Any reduction in emissions of NH_3 and NO_x will reduce *indirect* N_2O formation.

However, some techniques for reducing NH_3 emissions may lead to increased N_2O emissions from soils and animal housing. For instance, injection of manure into soils instead of surface spreading may reduce NH_3 emissions and related indirect N_2O emissions, but increase N_2O formation in agricultural soils. Similarly, some methods for reducing NH_3 emissions from animal housing may increase N_2O emissions.

The most effective way to avoid N_2O formation in agriculture is, therefore, by improving the efficiency of nitrogen use (Kroeze, 1996). This may result in a reduced N input to agricultural soils and, as a result, reduce formation of N_2O. In addition, it may reduce nitrogen leaching and runoff, thus reducing indirect emissions of N_2O.

4 SIMPLER METHODOLOGY

4.1 Ammonia

The simpler approach for estimating ammonia emissions from animal husbandry is to use an average emission factor per animal for each class of animal and to multiply this factor by the number of animals counted in the annual agricultural census. Table 4.1 presents the recommended ammonia emission factors for the different classes of animals. The ammonia emission factors are calculated for the average European farming situation, starting with an average nitrogen excretion per animal and using a volatilization percentage for ammonia losses in the housing and also volatilization factors for the remaining nitrogen entering the storage outside the building and for the nitrogen available for landspreading. Appendix A gives more details and also instructions how to account for emission control techniques.

The emission factors are calculated for one average animal which is present 365 days a year. Due to empty housing between two production cycles in practical farming situations, the number of animal places on a farm is greater than the average number of animals which are present on a yearly base at a farm. The average numbers of the different animal categories are counted by the annual agricultural census.

The ammonia emission caused by agricultural sources can be calculated by multiplying the average number of animals by the emission factor (Table 4.2). The default ammonia emission factors are given in Table 4.1. Every country can also use country specific factors; this can be the situation when more precise data are available on e.g. the nitrogen excretion per animal or the volatilisation percentages for ammonia losses. Appendix A (Table 3A) explains the derivation of the default ammonia emission factors, which can be helpful for calculating country specific factors.

Table 4.1: Ammonia emission factors for the simpler methodology to calculate the NH_3 emission from manure management. Annually averaged emission in kg NH_3 per animal, as counted in the annual agricultural census[1]

	Activity	N excreted	Animal housing	Storage outside the housing	Surface spreading of waste	Sum housing and manage-ment	Grazing	Total emissions
100901	Dairy cows	100	8.7	3.8	12.1	24.6	3.9	28.5
100902	Other cattle (including young cattle, beef cattle and suckling cows)	50	4.4	1.9	6.0	12.3	2.0	14.3
100903	Fattening pigs	14	2.89	0.85	2.65	6.39	0.0	6.39
100904	Sows[2]	36	7.43	2.18	6.82	16.43	0.0	16.43
100905 (+100911)	Sheep (and goats)[2]	20	0.24		0.22	0.46	0.88	1.34
100906 (+100912)	Horses (and mules, asses)	50	2.9		2.2	5.1	2.9	8.0
100907	Laying hens (laying hens and parents)	0.8	0.19	0.03	0.15	0.37	0.0	0.37
100908	Broilers (broilers and parents)	0.6	0.15	0.02	0.11	0.28	0.0	0.28
100909	Other poultry (ducks, geese, turkeys)	2.0	0.48	0.06	0.38	0.92	0.0	0.92
100910	Fur animals[2]	4.1	0.60		1.09	1.69	0.0	1.69
100913	Camels[3]	55				5.0	5.5	10.5
100914	Buffalo[3]	45				4.2	4.5	8.7

[1] This means explicitly not per animal place or per delivered animal.

[2] The emission factors are calculated for female adult animals; the emissions of the young animals are included in the given values.

[3] Preliminary data given in Bouwman et al. 1997

Table 4.2: Total ammonia emissions based on ammonia emission factors and animal class numbers, for manure management. Emission factors in kg NH_3 per animal, as counted in the annual agricultural census.

Activity		Ammonia emission factor				Number of Animals	Total ammonia emission D * E
		Housing	Storage	Application	Total A+B+C		
		A	B	C	D	E	F
100901	Dairy cows						
100902	Other cattle (including young cattle, beef cattle and suckling cows)						
100903	Fattening pigs						
100904	Sows (only female adult animals)						
100905	Sheep (only female adult sheep and goats)						
100906	Horses (horses, mules and asses)						
100907	Laying hens (laying hens and parents)						
100908	Broilers (broilers and parents)						
100909	Other poultry (ducks, geese, turkeys)						
100910	Fur animals (only female adult animals)						
	TOTAL						

4.2 Nitrous Oxide

Nitrous oxide emissions from manure management include (Table 2.2)

- emissions from manure management systems,
- direct soil emissions due to manure N-inputs, excluding manure,
- indirect emissions due to manure N-inputs.

In the following paragraph reference is made to several worksheets included in the IPCC-guidelines for National Greenhouse Gas Inventories. Worksheets 4-1 to 4-5 can be found in Volume 2 of the Workbook of the Revised 1996 IPCC Guidelines[1] (IPCC/OECD/IEA, 1997).

4.2.1 Emissions from manure management systems

These emissions are calculated in IPCC Worksheet 4-1, sheet 2 for 6 Animal Waste Management Systems (AWMS). The EMEP/CORINAIR sub-sector, however, is subdivided into 10 animal categories.

Recommended methodology (IPCC default methodology)

$$N\text{ex}_{\text{(AWMS)}} = \sum\nolimits_{\text{(T)}} [n_{\text{(T)}} \cdot N\text{ex}_{\text{(T)}} \cdot AWMS_{\text{(T)}}]$$

where

$N\text{ex}_{\text{(AWMS)}}$	nitrogen excretion rate per AWMS (kg a^{-1} N)
$n_{\text{(T)}}$	number of animals of type T in the country
$N\text{ex}_{\text{(T)}}$	N excretion rate of animals of type T in the country (kg animal^{-1} a^{-1} N); it is recommended to use national data rather than EMEP/CORINAIR default values given in Table 4.1 rather than the excretion rates given in Table 4-6 of the IPCC Workbook..
$AWMS_{\text{(T)}}$	fraction of $N\text{ex}_{\text{(T)}}$ that is managed in one of the different distinguished animal waste management systems for animals of type T in the country; it is recommended to use national data rather than the default values given in the IPCC Workbook, Table 4-7.

From this the total N_2O emission rate can be obtained as sum of the emission rates for each animal waste management system according to

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[1] The simpler methodology to assess nitrous oxide emissions was extracted in detail from the IPCC Guidelines and uses the IPCC terminology, symbols and units as far as possible. The terminology in the Good Practice Guidance (IPCC, 2000) Chapter 4.4, differs slightly from the Worksheet.

$$N_2O_{(\mathrm{AMWS})} = \sum [N\mathrm{ex}_{\mathrm{AWMS}} \cdot EF_{3(\mathrm{AWMS})}]$$

$N_2O_{(\mathrm{AWMS})}$	N_2O-N emission rate from all animal waste management systems in the country (in kg a^{-1} N)
$EF_{3(\mathrm{AWMS})}$	N_2O-N emission factor for a single AWMS (in kg kg^{-1} N, i.e. kg N_2O-N per kg *N*ex in the system). For $EF_{3(\mathrm{AWMS})}$, default values are listed in Table 4.3.

For N_2O emission rates the N_2O-N emission rates have to be multiplied by 44/28.

Table 4.3. IPCC default emission factors for N_2O emissions from manure management

Animal Waste Management System	Emission Factor $EF_{3(\mathrm{AWMS})}$ (kg N_2O-N per kg N excreted) [1]
Anaerobic lagoon	0.001 (< 0.002)
Liquid system	0.001 (< 0.001)
Daily spread	0.0
Solid storage & drylot	0.02 (0.005 - 0.03)
Pasture range & paddock[2]	0.02 (0.005 - 0.03)
Other	0.005

[1] see IPCC/OECD/IEA (1997) for default method to estimate N excretion per Animal Waste Management System

[2] to be included in SNAP CODE 100100/100200 (cultures with/without fertiliser)

4.2.2 Direct soil emissions due to manure N-inputs

Direct soil emissions induced by animal manure include emissions following use of manure as fertiliser. Emissions induced by grazing animals are included in SNAP Codes 100100 and 100200 (cultures with and without fertiliser).

Emission rates resulting from use of manure as fertiliser can be assessed as

$$N_2O_{\mathrm{AW,spread}} = EF_1 \cdot \sum\nolimits_{(\mathrm{T})} [n_{(\mathrm{T})} \cdot N_{\mathrm{AW,spread,(T)}}]$$

where

$N_2O_{\mathrm{AW,\ spread}}$	N_2O-N emission rate for the application of animal waste (kg a^{-1} N_2O-N)
EF_1	emission factor for direct emissions due to manure application (kg kg^{-1} N), as listed in Table 4.4
$n_{(\mathrm{T})}$	number of animals of type T in the country
$N_{\mathrm{AW,\ spread,\ (T)}}$	amount of N in excreta left for spreading (in kg animal^{-1} a^{-1} N) according to

$$N_{\mathrm{AW,spread,(T)}} = N\mathrm{ex}_{\mathrm{housing,(T)}} - NH_{3\mathrm{(T)}} \cdot \frac{14}{17}$$

where

$N\mathrm{ex}_{\mathrm{housing,\,(T)}}$	amount of N excreted in animal houses for an animal category T (in kg animal^{-1} a^{-1} N)
NH_3	NH_3 emission rate for an animal category T

For default values of $N\mathrm{ex}_{\mathrm{housing\,(T)}}$ and NH_3 use Appendix A, Table 3A.

4.2.3 Indirect emissions due to manure N-inputs

Indirect emissions due to manure N-inputs result from

- atmospheric emission and consecutive deposition of NH_3 and NO_x, and
- leaching of manure-N from soils to ground- and surface waters where N_2O formation takes place.

hence

$$N_2O_{\mathrm{indirect}} = N_2O_{\mathrm{G}} + N_2O_{\mathrm{L}}$$

where

N_2O_{indirect}	N_2O-N emission rates in the respective country due to NH_3 and NO_x losses from manure and mineral fertiliser application (kg a^{-1} N) [for kg a^{-1} N_2O multiply by 44/28]
N_2O_{G}	indirect emission rates due to deposition of reactive N species following agricultural emissions of NH_3 and NO (kg a^{-1} N)
N_2O_{L}	indirect emission rates due to leaching and runoff of reactive N species following application of manure and mineral fertiliser (kg a^{-1} N)

In the IPCC Workbook, ***indirect emissions due to NH_3 and NO_x emissions*** are calculated in IPCC Worksheet 4-5, sheet 4. Only indirect emissions due to manure spreading (excluding grazing animals) should be reported in this CORINAIR subsection. Table 4.4 summarises default emission factors.

Recommended methodology:

$$N_2O_{\mathrm{indirect}} = (NH_3 + NO) \cdot EF_4$$

where

NH_3	NH_3-N emission rates from manure and mineral fertiliser application (kg a^{-1} N). Emissions to be used from results obtained according to chapters 100900 – 5.1 or 4.1 and chapter 100100 – 4.1 of this Guidebook.
NO	NO-N emission rates from fertiliser application (kg a-1 N). Emissions to be used from results obtained according to chapter 100100 – 4.3 of this Guidebook.
EF_4	emission factor for indirect emissions due to manure and mineral fertiliser application (kg kg^{-1} N), as listed in Table 4.4

Indirect emissions due to leaching are calculated in IPCC Worksheet 4-5, sheet 5, and the manure-related part of this source can be estimated in a similar way.

Recommended methodology:

$$N_2O_{\mathrm{L}} = \left(N_{\mathrm{Fert}} + N\mathrm{ex}_{\mathrm{spread}}\right) \cdot Frac_{\mathrm{Leach}} \cdot EF_5$$

where

N_{fert}	total use of mineral fertiliser N in a country (see 100100)
$Frac_{\mathrm{Leach}}$	fraction of nitrogen input to soils that is lost through leaching and runoff (kg kg^{-1} N); default value $Frac_{\mathrm{Leach}} = 0.3$ kg kg^{-1}, see IPCC Workbook, Table 4-19.
EF_5	emission factor for indirect emissions due to leaching and runoff of fertilisers applied (kg kg^{-1} N), as listed in Table 4.4

Table 4.4. IPCC default emission factors EF_1 for N_2O emissions from agricultural soils to be reported under SNAP CODE 100900 (manure management)

	Emission Factor
Direct soil emissions - due to N input	$EF_1 = 0.0125$ (0.0025 - 0.0225) kg N_2O-N per kg N input[1]
Indirect emissions - NH_3 and NO_x deposition	$EF_4 = 0.01$ (0.002 - 0.02) kg N_2O-N per kg NH_3-N and NO_x-N emitted
- N leaching and runoff	$EF_5 = 0.025$ (0.002 - 0.12) kg N_2O-N per kg N leaching/runoff

[1] manure (excl. NH_3 emissions); see IPCC/OECD/IEA (1997) for default method to estimate N input

5 DETAILED METHODOLOGY

5.1 Ammonia

5.1.1 Introduction

It is anticipated that within the next two decades, ammonia from livestock manure will contribute over a quarter of all acidifying, and half of all eutrophying, emissions of atmospheric pollutants in Europe (Amann et al., 1996). International protocols therefore aim at a considerable reduction in ammonia emissions. Reduction potentials and reduction pathways have to be identified and quantified. This cannot be achieved by using mean emission factors or mean partial emission factors. In addition, the number and heterogeneity of small sources make accurate estimation of emissions from this sector particularly problematic. In recognition of these two factors, some considerable space in this guidebook is devoted to the detailed methodology for ammonia emissions from manure management. Despite the apparent complexity of the following tables, the method is easy to use in principle. It does necessarily require more input data than the simpler methodology.

The simpler method uses a simple process-based modelling approach, based on the concept of a flow of total ammoniacal nitrogen (TAN or mineral N) through the manure management system, as shown in the schematic diagram in Figure 5.1. The relative volumes of flow through the different pathways are determined by country-specific information on animal husbandry and manure management systems, while the proportion volatilised as ammonia at each stage in the system is treated as a percentage, based on measured values and expert judgement.

However, since it is clear that different manure management systems produce very different ammonia emissions, one of the major priorities in estimating emissions is to be able to distinguish between different systems. The adoption of a consistent flow model based on percentage transfers of ammoniacal N (TAN) allows different options or pathways to be incorporated in order to account for differences between real-world systems.

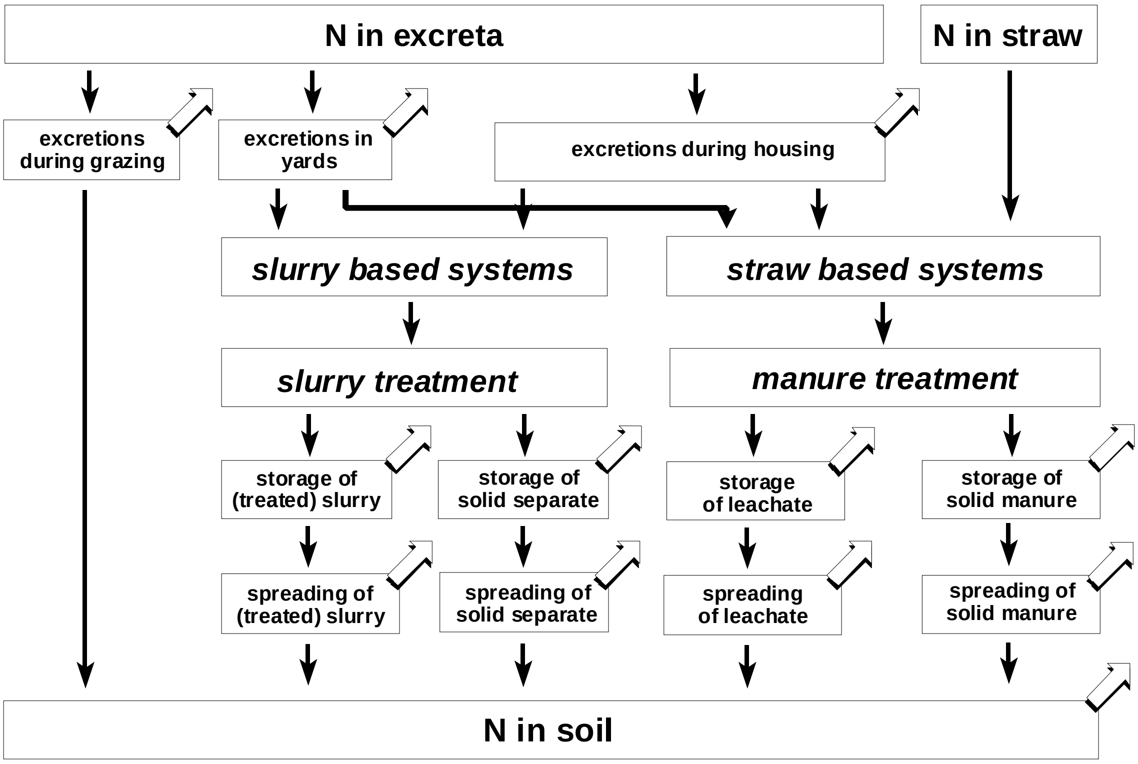
There are consequently several advantages over the simpler methodology:

- Different systems are represented at each stage to account for real differences in management systems and resulting emissions. In particular, distinctions are made between solid and liquid waste systems at each stage.
- Possible abatement measures are included as alternative systems. Measures have already been introduced in several countries in Europe, making current emission factors obsolete. In addition this enables efficient up-dating of emission estimates, and the systematic calculation of possible future emission projections and scenarios.
- Due to the hierarchical structure of the models, default values equivalent to those in the simpler method are available, so that no extra data is absolutely required. However, where information is available, it can be used systematically to improve emission estimates. This is likely to be particularly important where firm data is lacking but informed expert opinion (e.g. an estimate of the % of dairy farms producing slurry) may provide

reasonable approximations. For data-poor areas this is probably the most effective method of improving emission estimates.

- The tables (Appendix B) can also be provided as an active MS Excel spreadsheet with automatic calculation and error-checking.

Fig. 5.1: Flows of nitrogen and emissions of ammonia from animal husbandry (broad arrows indicate locations where ammonia is emitted)



5.1.2 Data sources and default values

Animal numbers

Even on SNAP level 3, animal numbers may be aggregated within categories (e.g. other cattle - sheep and goats – horses, mules and asses - other poultry). The assumptions made in the simpler methodology about the composition of these categories of sub-categories are unlikely to represent national or sub-national conditions. It is therefore advisable to disaggregate these categories within the bounds of the census data available, in particular

-	other cattle	calves and young cattle male and female beef cattle
-	sheep and goats	upland and lowland sheep goats
-	horses, mules and asses	heavy and light horses asses mules

-	other poultry	pullets male and female turkeys ducks geese

If necessary, other animals like buffalo, deer etc. will have to be dealt with separately, if they contribute significantly to the respective total.

Nitrogen excretion rates

Nitrogen excretion rates vary between countries according to livestock breeds, dietary inputs, slaughter age, and other aspects of animal husbandry. Rates are generally greater in more intensive systems, and relationships have been observed between nitrogen excretion and milk yield, for example (Eidgenössische Forschungsanstalt, 1997; Poulsen et al., 1998; Petersen et al., 1998; Döhler et al., 2002). Table 5A in Appendix B gives examples for nitrogen excretion rates.

Dietary manipulation may be used in some situations to reduce nitrogen excretion and resulting ammonia emission. Therefore, although it is not included as an abatement measure as such, the effect of dietary manipulation can be determined by adjusting the nitrogen excretion rate. This will mainly be of use in analysing possible future abatement scenarios.

Ammoniacal nitrogen content

As the detailed method makes use of the total ammoniacal nitrogen (TAN) when calculating emissions, the initial share of TAN must be known as well as any transformation rates between organic N and TAN. Table 5B gives examples of TAN shares in excreta.

Housing and grazing

Excreta may be dropped inside houses, on pastures and paddocks or on hard standings (i.e. “sealed” surfaces, such as roads, or waiting areas for cows to be milked). For cattle, the share of excreta deposited in these areas is equivalent to the share of time animals spent in the respective area.

Nitrogen input with bedding material

With bedding material (straw, chippings etc.) additional nitrogen has to be considered within the calculations. Table 5C gives examples of the magnitude of the amounts. The TAN share of nitrogen in straw is assumed to be zero.

Volatilisation rates

The volatilisation rates given in Table 5B in Appendix B can serve as examples; they were compiled from literature published on measured values (e.g. Isermann, 1990; Klaassen, 1992; ECETOC, 1994; Döhler et al., 2002), and from discussion between a range of experts from across Europe. In particular, values have evolved through several workshops on ammonia emissions under the UN/ECE Convention on Long-Range Transboundary Air Pollution; in Laxenburg, Austria (1991), Culham, UK (1994); Den Haag, Netherlands (1995); Reggio Emilia, Italy (1997), and Bern, Switzerland (2000).

Volatilisation rates from grazing may vary between animal categories and is a function of diet soil conditions. Examples are given in Table 5D.

Volatilisation rates from housing and storage vary with meteorological conditions, particularly temperature. In extreme cases it may be reasonable to adjust the rates by a small amount to account for this effect, but in general a uniform rate for the whole of Europe is acceptable within the overall uncertainty in emission estimates, and is useful in establishing a consistent and transparent methodology. Tables 5E and 5F may be used to derive national estimates for emissions from housing and storage of slurry and farmyard manure (FYM).

Volatilisation rates from application of manure to land are quite complex, and in addition to meteorological factors (see e.g. Menzi et al., 1998) , are influenced by soil type, soil moisture conditions, crop type and condition, and others. Since spatial variations in such factors are of similar magnitude at the micro scale as at the country scale, common values for Europe as listed in the simpler methodology are again to be replaced with national partial emission factors. The examples given in Tables 5G to 5I reflect the difficulties to deal with emissions from spreading in detail, as well as the different “philosophies” applied in different countries.

Normally, a relative emission rate is determined for a reference method (i.e. broadcasting of slurry at a given temperature). Abatement measure efficiencies are then defined as the amount by which implementation of a measure reduces emissions from a particular stage or process compared to the unabated or baseline situation. The values used in the tables reflect the state of knowledge obtained in particular in the UN/ECE Ammonia Expert Group (Menzi & Achermann, 2001).

Frequency distributions
In the detailed methodology, each single partial emission factor of the simpler methodology is replaced by a weighted mean of specific partial emission factors, using emission factors and the frequency distribution characterising the composition of the herds, in particular their performance and feeding regimes distributions, as well as the distribution of housing types, storage facilities and spreading practices. However, only matching triples of animal numbers, emission factors and frequency distributions can result in sensible results. Frequency distribution are least transferable. Therefore, no examples are given in Appendix B.

5.1.3 Outline of the calculation procedure

In principle, calculations depict the nitrogen and TAN flows as indicated in Fig. 5.1 by assessing the relevant amounts at each stage (TAN potential for emissions from grazing, TAN potential for emissions from hard standings, TAN potential for emissions from housing) and distribute these pools between the amounts emitted (emissions from grazing etc) and amounts remaining in the system and forming the next pool (TAN potential for emissions from slurry based systems etc.).

Disaggregation of animal categories, housing systems etc. has to be combined with a spatial and – wherever possible – temporal disaggregation, as the effects of pollution by air-borne ammonia and ammonium are local rather than national or regional. Wherever possible, small areas are to be considered rather than nations: frequency distributions have to be collected or modelled with a comparatively high resolution in space.

In practice, this results in rather complex calculation procedures. The UN/ECE Task Force on Emission Inventories and Projections will therefore offers their help to establish national calculation worksheets (For further information please contact the Task Force Secretariat or the Agriculture & Nature Expert Panel chair – see www.tfeip-secretariat.org for contact details).

5.2 Nitrous Oxide

No more detailed methodology is proposed for estimating emissions of N_2O. However, countries may use their own estimates for any step in the IPCC method if this will increase precision. In particular countries are encouraged to estimate NH_3 losses and N excretion by livestock using the methods described in this chapter, rather than the IPCC default values.

With the simpler methodology default ammonia emission factors are used. The detailed methodology makes use of country specific information on all the parameters involved like dietary information, local farming situations and use of low emission land spreading techniques. Volatilisation percentages can also be based on measurements of ammonia emissions from stables, storages and land application of wastes, as described in the ammonia methodology.

Once emissions have been calculated at whatever is determined by the national experts to be the most appropriate level of detail, results should also be aggregated up to the minimum standard level of information. This will allow for comparability of results among all participating countries. The data and assumptions used for finer levels of detail should also be reported to ensure transparency and replicability of methods.

6 RELEVANT ACTIVITY STATISTICS

6.1 Ammonia and animal numbers

For the simpler methodology, data is required on animal numbers for each of the categories listed in Table 4.2. The annual agricultural census can supply these data. Otherwise the statistical information from Eurostat can be used or the FAO Production Yearbook.

For the detailed methodology, the same data is required on animal numbers. Beside information is needed for all the parameters mentioned in Paragraph 5.1 (see also Appendices A and B).

6.2 Nitrous Oxide

The IPCC Guidelines (IPCC/OECD/IEA, 1997) provide default emission factors and other parameter values (N-excretion per animal, fraction of manure produced per animal waste management system, amount manure-N that leaches from soils, etc.) needed to estimate N_2O emissions from manure management. The only input data needed include animal numbers for six animal categories. These can be obtained from FAO databases.

7 POINT SOURCE CRITERIA

7.1 Ammonia

Emissions of ammonia should be considered on an area basis.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

8.1 Ammonia

Emission factors for the simpler methodology are listed in Appendix 1. For the detailed methodology, emission factors and their frequency distributions have to be derived nationally. Guidance is given in Appendix B.

8.2 Nitrous oxide

The simpler methodology provides tools for an estimate in chapter 5.

9 SPECIES PROFILES

10 UNCERTAINTY ESTIMATES

10.1 Ammonia and animal numbers

Uncertainties in ammonia emission factors are in the magnitude of 30 %.

Uncertainties in animal numbers per class of animals are in the magnitude of 10 %.

Animal numbers, (partial) emission factors and frequency distributions are likely to be biassed, data sets are often incomplete. For this edition of the Guidebook, no quality statements can be given other than those mentioned above. However, experts compiling animal numbers, national expert guesses for emission factors and frequency distributions are strongly requested to document their findings, decisions and calculus to facilitate reviewing of their respective inventories.

10.2 Nitrous Oxide

Although the bacterial processes leading to N_2O emissions (nitrification and denitrification) are reasonably well understood, it is as yet difficult to quantify nitrification and denitrification rates in terrestrial and aquatic systems. In addition, the observed fluxes of N_2O show large temporal and spatial variation. As a result, the estimates of national emissions of N_2O from manure management are relatively uncertain, as reflected in the ranges of the default emission factors. Mosier et al. (1998) applied the IPCC method to the world and estimated agricultural emissions with an uncertainty range of about a factor of 20: 1 - 19 Tg N_2O-N per year. This only reflects the uncertainty in emission factors. In addition, there is considerable uncertainty in other factors, including N excretion by animals and amount of N leaching from soils.

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

11.1 Ammonia

The simpler methodology applies a single average emission factor per animal. This takes no account of differing farming situations between countries or even in different areas of a particular country. On the other hand differing situations with regard to soil characteristics and temperature are also not taken into account.

At present, the detailed methodology is based on ammonia emission factors for individual countries or representative areas of Europe only.

11.2 Nitrous Oxide

The IPCC Guidelines was developed as a methodology applicable to any world country. As mentioned earlier, the IPCC method does not include the effects of soil type, fertiliser type, crop or climate on N_2O formation. Some European countries may, however, have access to country-specific data, making more reliable estimates possible. In some countries studies may have shown that country-specific conditions allow for adaptation of the emission factors. Or countries may apply process-based models to investigate their agricultural emissions of N_2O.

12 SPATIAL DISSAGGREGATION CRITERIA FOR AREA SOURCES

12.1 Ammonia

Considering the potential for ammonia to have local effects on ecology, ammonia emissions estimates should be disaggregated on the basis of animal husbandry data as much as possible. In The Netherlands or Germany for example the ammonia emissions are calculated per municipality and thereupon allotted to a grid of 5 by 5 km^2 or 50 by 50 km^2, respectively.

12.2 Nitrous Oxide

Spatial disaggregation of emissions from animal manure management systems may be possible if the spatial distribution of animal population is known. Soil maps may allow for disaggregation of soil emissions, if the spatial variation of N inputs is known. It may be difficult to disaggregate indirect emissions that take place at remote sites. With present emission partial factors, an accuracy is pretended which is unrealistic.

13 TEMPORAL DISAGGREGATION CRITERIA

13.1 Ammonia

The simpler methodology suffices with the ammonia emissions estimate without temporal disaggregation.

In the detailed methodology, first tools for a temporal disaggregation are provided (see this Guidebook, Vol. 1, chapter "The temporal variation of emission data and the GENEMIS project, BTMP-1 ff.).

13.2 Nitrous Oxide

Process-based models will be needed to quantify N_2O emissions dynamically. Soil emissions are known to take place shortly after fertilisation. However, considerable emissions may take place during fallow periods. Emissions from stables probably take place during all seasons. The timing of indirect emissions may be the most difficult to estimate, since there may be a considerable time lag between N excretion by animals and the eventual N_2O formation in aquatic systems due to N leaching and runoff.

14 ADDITIONAL COMMENTS

15 SUPPLEMENTARY DOCUMENTS

15.1 Ammonia

No supplementary documents are needed to calculate national ammonia emissions, as outlined for the simpler methodology. The scientific basis of the emission factors calculations is briefly reported in Appendix A (Van Der Hoek, 1998).

For the detailed methodology the documents of ECETOC (1994), the UN/ECE Working Group on Technology (Haanstra, 1995), the MARACCAS model (Cowell and ApSimon, 1998) or the GAS-EM model (Dämmgen et al., 2002) can be useful.

16 VERIFICATION PROCEDURES

17 REFERENCES

Amann, M., Bertok, I., Cofala, J., Gyarfas, F. Heyes, C., Klimont, Z. and Schöpp, W., 1996. Cost-effective control of acidification and ground-level ozone. 2nd Interim Report to the European Commission DG-XI. IIASA, Laxenburg, Austria.

Amon, B., Amon, Th., Boxberger, J., 1998. Untersuchungen der Ammoniakemissionen in der Landwirtschaft Österreichs zur Ermittlung der Reduktionspotentiale und Reduktionsmöglichkeiten. Final report. Forschungsprojekt Nr. L 883/94 im Auftrag des Bundesministeriums für Land- und Forstwirtschaft. Universität für Bodenkultur, Institut für Land-, Umwelt- und Energietechnik, Wien.

Asman, W.A.H., 1992. Ammonia emission in Europe: updated emission and emission variations. RIVM report 228471008. RIVM, Bilthoven, The Netherlands.

Besluit gebruik dierlijke meststoffen, 1991. Besluit van 13 juli 1991, houdende wijziging van het Besluit gebruik dierlijke meststoffen. Staatsblad, nummer 385, The Hague, The Netherlands.

Brewer, A.J. and I.A. Davidson, 1999. Developing Agricultural Controls Under Integrated Pollution Prevention Control (IPPC) in England. In: Kuratorium für Technik und Bauwesen in der Landwirtschaft (ed.): Regulation of Animal Production in Europe. International Congress in Wiesbaden, May 9-12, 1999. Landwirtschaftsverlag, Münster-Hiltrup. Pg. 203-207.

Bouwman A.F., 1996. Direct emissions of nitrous oxide from agricultural soils. Nutrient Cycling Agroecosystems 46, 53-70.

Bouwman, A.F., Lee, D.S., Asman, W.A.H. Dentener, F.J., van der Hoek, K.W., Oliver, J.G.J., 1997. A global high-resolution emission inventory for ammonia. Global Biogeochemical Cycles 11, 561-587.

Cowell, D.A., ApSimon, H.M., 1998. Cost-effective strategies for the abatement of ammonia emissions from European agriculture. Atmos. Environ. 32, 573-580.

Dämmgen, U., Lüttich, M., Döhler, H., Eurich-Menden, B., Osterburg, B., 2002. GAS-EM – a procedure to calculate gaseous emissions from agriculture. Landbauforschung Völkenrode 52, 19-42.

Döhler, H., Eurich-Menden, B., Dämmgen, U., Osterburg, B., Lüttich, M., Bergschmidt, A., Berg, W., Brunsch, R., 2002. BMVEL/UBA-Ammoniak-Emissionsinventar der deutschen Landwirtschaft und Minderungsszenarien bis zum Jahre 2010. Texte 05/02. Umweltbundesamt, Berlin.

Düngeverordnung, 1996. Verordnung über die Grundsätze der guten fachlichen Praxis beim Düngen. Bundesgesetzblatt Part I, dd February 6, 1996, p. 118; modified in Bundesgesetzblatt, Part I, dd July 1996, p. 1836.

ECETOC, 1994. Ammonia emissions to air in western Europe. Technical Report 62. European Centre for Ecotoxicology and Toxicology of Chemicals, Brussels.

Eidgenössische Forschungsanstalt für Agrarökologie und Landbau Zürich-Reckenholz, Institut für Umweltschutz und Landwirtschaft Liebefeld (eds.), 1997. Ammoniak-Emissionen in der Schweiz: Ausmass und technische Beurteilung des Reduktionspotentials. Schriftenreihe FAL 26. Eidgenössische Forschungsanstalt für Agrarökologie und Landbau, Zürich.

Freibauer, A., Kaltschmitt, M. (eds), 2001. Biogenic Greenhouse Gas Emissions from Agriculture in Europe. European Summary Report (Project Report Task 3) of the EU Concerted Action FAIR3-CT96-1877 “Biogenic Emissions of Greenhouse Gases Caused by Arable and Animal Agriculture”, Universität Stuttgart, Institut für Energiewirtschaft und Rationelle Energieanwendung, Stuttgart.

Haanstra, H., 1995. Reduction of ammonia emissions from agricultural sources (livestock). Discussion paper for review group of the UNECE Working Group on Technology. Ministry of Housing, Spatial Planning and Environment, The Hague, The Netherlands.

IPCC, 1995. Climate Change 1994. Radiative Forcing of Climate Change and an Evaluation of the IPCC IS92 Emission Scenarios. Intergovermental Panel on Climate Change. Edited by J.T. Houghton, L.G. Meira Filho, J. Bruce, Hoesung Lee, B.A. Callander, E. Haites, N. Harris and K. Maskell.

IPCC/OECD/IEA, 1997. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. OECD, Paris.

IPCC, 2000. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Institute for Global Environmental Strategies (IGES), Hayama.

Isermann, K., 1990. Ammoniakemissionen der Landwirtschaft als Bestandteil ihrer Stickstoffbilanz und Lösungsansätze zur hinreichenden Minderung. In: Kuratorium für Technik und Bauwesen in der Landwirtschaft (KTBL) (ed.), Ammoniak in der Umwelt, Landwirtschaftsverlag, Münster-Hiltrup. Pg. 1.1-1.76.

Jakobsson, C., 1999. Ammonia Emissions – Current Legislation Affecting the Agricultural Sector in Sweden. In: Kuratorium für Technik und Bauwesen in der Landwirtschaft (ed.): Regulation of Animal Production in Europe. International Congress in Wiesbaden, May 9-12, 1999. Landwirtschaftsverlag, Münster-Hiltrup. Pg. 208-213.

Koch, W.W.R., van Harmelen, A.K., Draaijers, G.P.J., van Grootfeld, G, 2001: Emission data for The Netherlands 1998 and Estimates for 1999.Rapportagereeks Doelgroepmonitoring 7, Jan. 2001. Inspectorate for Environmental Protection, Department for Monitoring and Information Management, ‘s-Gravenhage.

Kroeze C., 1996. Inventory of strategies for reducing anthropogenic emissions of N_2O and potential reduction of emissions in the Netherlands. Mitigation and Adaptation Strategies for Global Change 1, 115-137.

Menzi, H., Achermann, B. (eds), 2001. UN/ECE Ammonia Expert Group. Berne, 18-20 September 2000. Proceedings. Environmental Documentation No. 133. Air. Swiss Agency for the Environment, Forest and Landscape (SAEFL), Bern.

Menzi, H.; Katz, P.E.; Farni, M.; Neftel, A.; Fruck, R., 1998. A simple empirical model based on regression analysis to estimate ammonia emissions after manure application. Atmos. Environ. 32, 301-307.

Mosier A., Kroeze, C., Nevison, C., Oenema, O., Seitzinger, S., 1998. Closing the global atmospheric N_2O budget: nitrous oxide emissions through the agricultural nitrogen cycle. (OECD/IPCC/IEA Phase II Development of IPCC Guidelines for National Greenhouse Gas Inventories). Nutrient Cycling Agroecosystems 52, 225-248.

Pain, B.F., Misselbrook, T.H., Jarvis, S.C., Chambers, B.J., Smith, K.A., Webb, J., Phillips, V.R., Sneath, R.W., Demmers, T.G.M., 2000. Inventory of Ammonia Emission from UK Agriculture 1998. Report of MAFF Contract WA0630. IGER, North Wyke.

Pain, B. F., Van der Weerden, T. J., Chambers, B. J., Phillips, V. R. & Jarvis, S. C., 1998. A new inventory for ammonia emissions from UK agriculture. Atmos. Environ. 32, 309-313.

Petersen, S.O., Sommer, S.G., Aaes, O., S∅egaard, K., 1998. Ammonia losses from urine and dung of grazing cattle: effect of N intake. Atmos. Environ. 32, 295-300.

Poulsen, H.D., Kristensen, V.F. (eds), 1998. Standard Values for Farm Manure. A Reevaluation of the Danish Standard Values concerning the Nitrogen, Phosphorus and Potassium Content of Manure. DIAS report 7 (1). Danish Institute of Agricultural Sciences, Tjele.

Van Der Hoek, K.W., 1994. Berekeningsmethodiek ammoniakemissie in Nederland voor de jaren 1990, 1991 en 1992. RIVM report 773004003. RIVM, Bilthoven, The Netherlands.

Van Der Hoek, K.W., 1997. Calculation of N-excretion and NH_3 emission by animal production on European and global scale. RIVM report in preparation. RIVM, Bilthoven, The Netherlands.

Van Der Hoek, K.W., 1998. Estimating ammonia emission factors in Europe: summary of the work of the UNECE ammonia expert panel. Atmospheric Environment 32, 315-316.

18 BIBLIOGRAPHY

19 RELEASE VERSION, DATE AND SOURCE

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Date: 2002

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APPENDIX A

EXPLANATION OF THE AMMONIA EMISSION FACTORS USED IN THE SIMPLER METHODOLOGY TO CALCULATE THE EMISSION OF AMMONIA

This appendix gives more detailed information about the default ammonia emission factors and the categories of animals. These parameters are necessary to calculate the national emission of ammonia by agricultural sources. The calculation starts with the average nitrogen excretion of the animal. Ammonia losses during housing, storage of manure outside the building, grazing and application of manure are calculated as a volatilisation percentage of the 'incoming' amount of nitrogen. This means that when for example a slurry storage tank is covered, the volatilisation percentage declines and the amount of nitrogen available for landspreading increases and consequently the emission of ammonia during spreading also increases.

The volatilisation percentages for stables are derived from the Dutch ammonia emission factors for animal housing. These emission factors are based on measurements during the winter season for dairy cattle and during a full year for pigs and poultry. The volatilisation percentages for slurry storage tanks and landspreading originate from research in the United Kingdom and The Netherlands. For landspreading it is assumed that all slurries and solid wastes are spread on the field without using techniques to reduce emissions of ammonia.

The simpler methodology for calculating ammonia emissions uses default emission factors as presented in Table 3 (Chapter 4.1). The underlying data for these ammonia emission factors are presented in this Appendix in Table 3A. With the detailed methodology for every parameter a country specific value can be used. When an emission reduction technique is applied with an emission reduction for example of 80 %, the corresponding volatilisation percentage has to be multiplied with 0.2.

Number of animals

The default ammonia emission factors have to be used in relation to the average number of animals in a certain year. This number of animals is obtained from the annual agricultural census. This means that the number of animal places or the number of delivered animals is not relevant in respect to the presented default emission factors. For example a farm with 100,000 animal places for broilers counts 75,000 broilers as an average number of animals. This is due to a production cycle of 8 weeks, consisting of 6 weeks animal production followed by 2 weeks cleaning of the housing.

Dairy cows

The nitrogen excretion of a dairy cow depends on many factors. First of all there is a difference in milk production (and feeding level) per dairy cow within and between the European countries. Further the amount of nitrogen fertiliser applied to pasture varies and hence the nitrogen content of the grass. This means that the nitrogen intake and excretion per dairy cow also differs within and between countries. The nitrogen excretion of 100 kg per year is based on an European averaged milk yield of about 4500 kg milk per dairy cow per year and on a moderate use of fertiliser. It appears that for most countries this figure is quite reasonable. Dairy cows in calf are considered as dairy cows.

Also the length of the grazing period varies and hence the ratio nitrogen excreted in the pasture and nitrogen excreted in the housing. The grazing period is set at about 180 days and the corresponding nitrogen excretion is 50 kg of nitrogen. The dairy cows however remain a couple of hours a day in the housing for milking, so it is assumed that 20 % of the excreted nitrogen is collected in the housing. Effectively 40 kg of nitrogen are excreted in the pasture and 60 kg in the housing.

Slurry based systems store the wastes under a slatted floor inside the building and/or in slurry storage tanks outside the building. When all the slurry is stored outside the building, there is still a considerable emission of ammonia from the stable due to permanent presence of wastes in the building. The ammonia losses in the storage outside the building are based on an open storage tank that is in use for 6 months per year and as mentioned not provided with a cover.

When solid farmyard manure is produced the emission from housing is likely to be smaller but the emission from the farmyard manure pile is greater. In the simpler methodology, it is assumed that emissions of ammonia are equal to slurry based systems. However, in the detailed methodology distinctions are made between solid and liquid waste systems.

The emissions from landspreading are based on slurries. With solid wastes the percentage of mineral nitrogen is lower than in slurries, but in contrast to slurries, there is no rapid infiltration into the soil. It is therefore assumed that emissions from landspreading of solid wastes are equal to slurry based systems. The detailed methodology assumes differences in ammonia emission between the two systems.

Other cattle

Thirty-six percent of European cattle are dairy cows and the remainder are categorised as 'other cattle'. The composition of the other cattle is assumed as:

- 39 % young cattle for replacement with a nitrogen excretion of 46 kg (stable 24 kg and pasture 22 kg);
- 10 % suckling cows with a nitrogen excretion of 80 kg (stable 35 kg and pasture 45 kg);
- 15 % beef cattle housed all year with a nitrogen excretion of 40 kg.

This results in an average annual nitrogen excretion of 50 kg pro animal, of which 30 kg in the stable and 20 kg on pasture. The figures in Table 4A (Appendix A) deal with slurry based systems. As indicated for dairy cows the emissions of ammonia from solid manure based systems are supposed to be equal to slurry based systems.

Sheep

The number of sheep varies during the year due to lambing in spring. Therefore the figures in Table 3A are based on a ewe, including 1-1.5 adherent lambs. The combined excretion of the ewe and lambs is 20 kg of nitrogen per year. If the number of ewes is not known from the agricultural census, the following approach can be used. Is the agricultural census performed around December then about 75 % of the counted sheep are ewes. For agricultural census data around May about 50 % of the counted sheep are ewes.

Horses, mules and asses

The figures in Table 3A are meant as an average for adult as well as for young animals.

Pigs and poultry

As far as these animals are kept indoors, the conditions are more or less comparable over Europe. Therefore it is assumed that for pigs and poultry the Dutch situation can be used for the other European countries, although it is recognised that the size of pig and poultry units differs considerably between countries. There are also differences between countries in the ages, and hence size and annual N excretion, at which animals are slaughtered.

For all animal categories in Table 3A the emission factors are calculated for use with the number of animals counted in the agricultural census. The number of animal places is for pigs and poultry often 10-20 % higher due to vacancy of the house between two consecutive animal production periods. It is important to note that the data from the agricultural census have to be used.

For pigs liquid manure systems are assumed. The ammonia losses in the storage outside the building are based on an open storage tank in use for 6 months per year.

Solid manure based systems maybe give less emission in the stable, but depending on the structure of the pile, storage emissions can be greater (a loose pile gives increased emissions). Total emissions of ammonia are assumed to be the same for slurry based and solid manure based systems in the simpler methodology. According to the detailed methodology the systems differ in ammonia emission.

Table 3A presents calculations for fattening pigs and for a sow with her piglets until 20 kg and 0.3 young sows. The nitrogen excretion of the sow and piglets is 32 kg per year and the 0.3 young sows add 4 kg of nitrogen per year. This means that the emission factors have to be multiplied with the number of fattening pigs and sows as they are counted in the agricultural census. If the agricultural census only gives an 'overall' figure for pigs, then approximately 50 % of the animals are fattening pigs and 10 % are sows. The remainder of the animals are piglets etc. and their emissions of ammonia are already included in the ammonia emissions of the sows.

About 50 % of the laying hens producing eggs are kept on liquid manure systems. The remaining laying hens, their parent animals and the broilers have solid manure based systems. In the simpler methodology the ammonia emissions from liquid manure and solid manure based systems are assumed to be the same.

The figures for other poultry are based on the values for turkeys.

Simpler methodology for whole animal classes

When statistical data are lacking for some animal categories as used in Tables 3 and 4 the following approach can be applied.

For cattle it can be assumed that approximately 36 % of the herd are dairy cows and 64 % are other cattle like young cattle, beef cattle and suckling cows.

From the total number of pigs about 50 % are fattening pigs (heavier than circa 20 kg) and about 10 % are sows. The remainder of the pigs are young sows and piglets and their ammonia emissions are already included in the emissions of the sows.

For poultry is it more complex to make a subdivision. Using a very rough estimation 45 % of the poultry are laying hens, 50 % broilers and 5 % other poultry. However there can be a big variation in this subdivision from country to country.

References

Bode, M.J.C. de, 1991. Odour and ammonia emissions from manure storage. In: Nielsen, V.C., Voorburg, J.H., L'Hermite, P. (eds.): Odour and ammonia emissions from livestock farming. Elsevier, London. Pp 59-66.

Bouwman, A.F., D.S. Lee, W.A.H. Asman, F.J. Dentener, K.W. Van Der Hoek, J.G.J. Olivier, 1997. A global high-resolution emission inventory for ammonia. Global Biogeochemical Cycles 11, 561-587.

Groot Koerkamp, P.W.G., 1994. Review on emissions of ammonia from housing systems for laying hens in relation to sources, processes, building design and manure handling. J. agric. Engng Res. 59, 73-87.

Jarvis, S.C., D.W. Bussink, 1990. Nitrogen losses from grazed swards by ammonia volatilization. In: Gáborcik, N., Krajcovic, V., Zimková, M. (eds.): Soil-Grassland-Animal Relationships, Proceedings 13th General Meeting of the European Grassland Federation. The Grassland Research Institute, Banská Bystrica. Pp 13-17.

Kroodsma, W., J.W.H. Huis in 't Veld, R. Scholtens, 1993. Ammonia emission and its reduction from cubicle houses by flushing. Livestock Production Science 35, 293-302.

Molen, J. van der, D.W. Bussink, N. Vertregt, H.G. van Faassen, D.J. den Boer, 1989. Ammonia volatilization from arable and grassland soils. In: Hansen, J.A., Henriksen, K. (eds.): Nitrogen in organic wastes applied to soils.. Academic Press, London. Pp 185-201.

Oosthoek, J., W. Kroodsma, P. Hoeksma, 1991. Ammonia emission from dairy and pig housing systems. In: Nielsen, V.C., Voorburg, J.H., L'Hermite, P. (eds.): Odour and ammonia emissions from livestock farming. Elsevier, London. Pp 31-42.

Table 4A. Default ammonia emission factors for manure management.

	Ratio[1]	kg N	kg NH_3	Ratio[1]	kg N	kg NH_3
	100901 Dairy cows			100902 Other cattle		
N excretion in housing		60.00			30.00	
Emission in housing	12 %	7.20	8.7	12 %	3.60	4.4
N in outside storage		52.80			26.40	
Emission in outside storage	6 %	3.17	3.8	6 %	1.58	1.9
N available for landspreading		49.63			24.82	
..... of which mineral N[2]	50 %	24.82		50 %	12.41	
Emission of landspreading	40 %	9.93	12.1	40 %	4.96	6.0
Total ammonia emission			28.5			14.3
	100903 Fattening pigs			100904 Sows[3]		
N excretion in housing		14.00			36.00	
Emission in housing	17 %	2.38	2.89	17 %	6.12	7.43
N in outside storage		11.62			29.88	
Emission in outside storage	6 %	0.70	0.85	6 %	1.79	2.18
N available for landspreading		10.92			28.09	
..... of which mineral N[2]	50 %	5.46		50 %	14.04	
Emission of landspreading	40 %	2.18	2.65	40 %	5.62	6.82
Total ammonia emission			6.39			16.43
	100905 Sheep[3]			100906 Horses		
N excretion in housing		2.00			20.00	
Emission in housing	10 %	0.20	0.24	12 %	2.40	2.9
N in outside storage		1.80			17.60	
N available for landspreading		1.80			17.60	
.... of which mineral N[2]	20 %	0.36		20 %	3.52	
Emission of landspreading	50 %	0.18	0.22	50 %	1.76	2.2
Total ammonia emission			1.34			8.0
	100907 Laying hens			100908 Broilers		
N excretion in housing		0.80			0.60	
Emission in housing	20 %	0.16	0.19	20 %	0.12	0.15
N in outside storage		0.64			0.48	
Emission in outside storage	4 %	0.03	0.03	3 %	0.01	0.02
N available for landspreading		0.61			0.47	
.... of which mineral N[2]	40 %	0.25		40 %	0.19	
Emission of landspreading	50 %	0.12	0.15	50 %	0.09	0.11
Total ammonia emission			0.37			0.28
	100909 Other poultry			100910 Fur animals[3]		
N excretion in housing		2.00			4.10	
Emission in housing	20 %	0.40	0.48	12 %	0.49	0.60
N in outside storage		1.60			3.61	
Emission in outside storage	3 %	0.05	0.06			
N available for landspreading		1.55			3.61	
.... of which mineral N[2]	40 %	0.62		50 %	1.80	
Emission of landspreading	50 %	0.31	0.38	50 %	0.90	1.09
Total ammonia emission			0.92			1.69

[1] Ratio N volatilised as NH_3-N volatilised / N in animal waste

[2] N in animal waste consists of mineral N (available for volatilisation) and organic N. In liquid manure N contains about 50 % mineral N; solid manure contains a lower percentage of mineral N

[3] The values are calculated for female adult animals; the emissions of the young animals are included in the given values

APPENDIX B

TABLES FOR THE CALCULATION OF THE EMISSION OF AMMONIA ACCORDING TO THE DETAILED METHODOLOGY.

Table 5A Nitrogen excretion rates

	Range [1]	Spain [2]	Nether-lands	UK [3]	Denmark [4]	Switzer-land [5]	Germany [6]
Mammals	kg place^{-1} a^{-1} N				kg animal^{-1} a^{-1} N	kg place^{-1} a^{-1} N	kg place^{-1} a^{-1} N
Dairy cows, less than 5000 kg a^{-1} milk	60 – 110						
Dairy cows, 5000 to 6000 kg a^{-1} milk, low amount of concentrate	100 – 140						
Dairy cows, 5000 to 6000 kg a^{-1} milk, > 500 kg a^{-1} concentrate	80 – 100						
Dairy cows, 9000 to 10000 kg a^{-1} milk	110-140						
Dairy cows		60.23	134.0				
Dairy cows and heifers				106		105	
Dairy cows, heavy breed					128		115
Dairy cows, Jersey					107		
Mutterkühe							96
Suckling cows			111.3				
Dairy heifers in calf				58			
Beef cattle, extensive, mainly grazing	40 – 50						
Beef cattle, intensive, maize silage	30 – 40						
Beef cows and heifers		43.8		61			
Beef heifers in calf				58			
Bulls > 2 a			105.8	84			
Bulls 1 – 2 a		43.8	105.8	56			
Beef > 2 a				72			
Beef cattle		50.19				60	
Beef cattle male, 1 – 2 a			58.0				42
Beef cattle female, 1 – 2 a			89.8				44
Calves < 1 a				29			16
Breeding sows incl. piglets	30 – 40	14.79	29.8	30.0			
Dry sows				15.6			
Sows until weaning					25.7		
Sows + 21 pigs of 25 kg					36.7		
Sows plus litter (plus boar)						35	36
Boars			22.4	15.6			
Fatteners > 110 kg				15.6			
Fatteners, 25 – 100 kg, no phase feeding	15 – 18						

Table 5A Nitrogen excretion rates (continued)

	Range[1]	Spain[2]	Netherlands	UK[3]	Denmark[4]	Switzerland[5]	Germany[6]
Fatteners, 25 – 100 kg, with phase feeding	12 – 15						
Fatteners, 25 – 100 kg, with phase feeding and pure amino acids	10 – 14						
Fatteners 20 – 110 kg				15.6			
Growing pigs 20 – 50 kg		5.76	13.4				
Slaughter pigs 25 – 95 kg					3.25		
Fattening pigs		8.5				15	11.5
Weaners < 20 kg				2.3			
Sheep						16	13
Adult sheep		10.22					
Ewes			26.0	11.0			
Lambs		2.92		1.7			
Goats						18	
Adult goats		8.76	22.4				
Growing kids		2.19					
Horses		25.55				60	50
Horses, weight 400 kg					38		
Horses, weight 600 kg					50		
Horses, weight 800 kg					63		
Mink and ferret			3.5		0.895		
Fox and finnracoon			9.0		0.895		
Rabbits			8.1				
Poultry							
Laying hens	0.60 – 0.80	0.6		0.85		0.71	0.74
Laying hens < 18 weeks			0.33				
Laying hens > 18 weeks			0.69				
Hens in battery cage systems					0.742		
Deep litter hens					0.854		
Free-range hens					0.813		
Organic hens					0.917		
Broilers	0.35 – 0.50	0.3	0.57	0.60		0.40	0.29
Pullets				0.40		0.34	
Breeding hens				1.1			
Turkeys (male)				1.88			
Turkeys (female)				1.00			
Turkeys			1.97			1.4	1.5
Turkeys for breeding < 7 months			2.52				
Turkeys for breeding > 7 months			3.04				
Geese							0.73
Ducks			1.09	1.2			0.60

[1] Menzi & Achermann, 2001; [2] Spanish Ministry of Agriculture, 2001; [3] Webb, 2000; [4] Poulsen & Kristensen, 1998; [5] Eidgenössische Forschungsanstalt, 1997; [6] Döhler et al., 2002.

Table 5B: TAN content in excreta

	UK [1)]	Switzerland [d)]	Germany [e)]
Mammals	kg kg^{-1} N	kg kg^{-1} N	kg kg^{-1} N
Cattle	0.60		0.50
Cattle, slurry		0.60	
Cattle, slurry poor in solids		0.70	
Pigs	0.70	0.75	0.66
Sheep	0.60		
Goats			
Horses		0.40	0.40
Poultry			
Laying hens	0.70		0.70
Broilers			0.70
Turkeys	0.70		
Geese	0.70		
Ducks	0.70		

[1] Webb, 2001; [2] Eidgenössische Forschungsanstalt, 1997; [3] Döhler et al., 2002.

Table 5C: Exemplary nitrogen inputs with straw

	UK [1)]	Germany [2)]
	kg animal^{-1} a^{-1} N	kg place^{-1} a^{-1} N
Cattle		
Dairy cows and heifers	6.0	
Dairy cows, tied systems and cubicles		7.8
Dairy cows, deep litter		13.8
Beef 1 – 2 years	3.6	
Beef cattle, tied systems		4.6
Beef cattle, deep litter		8.8
Pigs		
Sows plus litter	2.4	8.3
Fatteners 20 – 110 kg	0.8	
Fatteners, deep litter		1.4
Fatteners, free ventilated boxes		0.7
Sheep		
Lowland sheep	0.24	
Horses		12.6

[1] Webb, 2001; [2] Döhler et al., 2002.

Table 5D: Partial emission factors grazing (expressed as share of TAN or total N available)

	Spain [1)]	UK [2)]	Switzerland [3)]	Germany [4)]
Mammals		kg kg^{-1} N	kg kg^{-1} N	kg kg^{-1} N
	Total N	TAN	Total N	Total N
Cattle	0.08		0.05	0.08
Dairy cows and heifers		0.130		
Dairy heifers in calf		0.157		
Beef cows and heifers		0.057		
Pigs				
Sheep	0.046		0.05	0.08
Lowland ewes		0.113		
Upland ewes		0.034		
Lambs		0.236		
Goats	0.046		0.05	
Horses	0.08		0.05	0.08

[1] Spanish Ministry of Agriculture, 2001; [2] Webb, 2001; [3] Eidgenössische Forschungsanstalt, 1997; [4] Döhler et al., 2002.

Table 5E: Exemplary partial emission factors housing (expressed as share of TAN or total N available)

		Denmark 1)	Switzer-land 2)	Germany 3)
Mammals		kg kg^{-1} N	kg kg^{-1} N	kg kg^{-1} N
			Total N	Total N
Cattle	Slurry		0.07	
	FYM		(1)	
Dairy cows and heifers	Slurry	0.313		
	FYM	0.236		
Beef 1 – 2 years	Slurry	0.285		
	FYM	0.234		
Dairy and beef cattle, tied systems	Slurry			0.04
	FYM			0.039
Dairy and beef cattle, and beef cubicles	Slurry			0.118
	FYM			0.118
Dairy and beef cattle deep litter	FYM			0.127
Pigs	Slurry		0.15	
	FYM		(2)	
Sows plus litter	Slurry	0.235		0.167
	FYM	0.275		0.167
Fatteners 20 – 110 kg	Slurry	0.278		
	FYM	0.306		
Fatteners, insulated houses	Slurry			0.23
Fatteners, deep litter, insulated houses	FYM			0.33
Fatteners, free ventilated boxes	FYM			0.17
Sheep	FYM		(1)	
Lowland sheep	FYM	0.258		
Goats			(1)	
Horses			(1)	
Poultry				
Laying hens		0.335		
Dung pit			0.6	0.337
Dung belt			0.2	
	Without drying			0.162
	With drying			0.042
Broilers		0.256	0.4	0.138
Geese				0.548
Ducks				0.5
Turkeys male		0.361		0.4
Turkeys female		0.339		0.4

(1) 7 % of total N + 30 % of the remaining TAN
(2) 15 % of total N + 30 % of the remaining TAN

[1] Poulsen & Kristensen, 1998; [2] Eidgenössische Forschungsanstalt, 1997; [3] Döhler et al., 2002.

Table 5F: Exemplary NH_3-N losses from storage

		UK 1)	Switzer-land 2)	Germany 3)	Germany 3)
		kg kg^{-1} N	kg kg^{-1} N	kg kg^{-1} N	kg kg^{-1} N
		TAN	TAN	TAN	Total N
Cattle					
Slurry			0.15		
Slurry	Tank	0.069			
	Open tank				0.080
	Solid cover				0.008
	Natural crust				0.024
	Floating cover, chaff				0.016
	Floating cover, granules and film				0.012
	Lagoon	0.438			0.150
	Storage inside building underneath slatted floor				0.024
FYM			0.30	0.60	
Pigs					
Slurry			0.12		
Slurry	Tank	0.040			
	Open tank				0.150
	Solid cover				0.015
	Natural crust				0.105
	Floating cover, chaff				0.030
	Floating cover, granules and film				0.023
	Lagoon	0.28			0.25
	Storage inside building underneath slatted floor				0.10
FYM		0.021	0.30	0.60	
Horses			0.30	0.60	
FYM					
Laying hens		0.22	0.20	0.04	
Broilers		0.37	0.10	0.03	

[1] Webb, 2001; [2] Eidgenössische Forschungsanstalt, 1997; [3] Döhler et al., 2002.

Table 5G: Exemplary partial NH_3 emission factors for spreading of slurry and farmyard manure, United Kingdom inventory (expressed as share of TAN, Pain et al., 1997)

	Incorporation	Cattle and pigs			Sheep	Layers	All other poultry
Slurry		DM < 4 %	4 % < DM < 8 %	DM > 8 %			
Broadcast 1)							
August to April	Without	0.15	0.37	0.59			
	Within 1 day	0.105	0.259	0.413			
	Within 1 week	0,135	0.333	0.53			
Summer	Without	0.60	0.60	0.60			
	Within 1 day	0.42	0.42	0.42			
	Within 1 week	0.54	0.54	0.54			
FYM							
Broadcast							
All year	Without	0.76			0.76	0.45	0.45
	Within 1 day	0.342				0.158	0.045
	Within 1 week	0.57				0.315	0.113

1) % reduction of EF for bandspreading and trailing shoe: 0 %, for injection 80 %

Table 5H: Exemplary partial NH_3 emission factors for spreading of slurry and farmyard manure, mean soil temperature 15 °C, German inventory (expressed as share of TAN, Döhler et al. 2002)

	Animal category	Cattle		Pigs		Poultry
	Applied to	Arable land	Grassland	Arable land	Grassland	Arable land
Slurry						
	Incorporation within					
Broadcast	1 h	0.10		0.04		
	4h	0.26		0.09		
	6h	0.35		0.11		
	12	0.44		0.16		
	24	0.46		0.21		
	48	0.50		0.25		
	No incorp.	0.50	0.60	0.25	0.30	
Trailing hose	1 h	0.04		0.02		
	4h	0.15		0.06		
	6h	0.20		0.08		
	12	0.30		0.11		
	24	0.39		0.14		
	48	0.46		0.17		
	Bare soil, no incorporation	0.45		0.18		
	Vegetation < 0.3 m	0.63	0.60	0.25	0.21	
	Vegetation > 0.3 m	0.35	0.60	0.13	0.30	
Trailing shoe			0.60		0.15	
Open slot			0.54		0.12	
Solid manure						
Broadcast	1 h	0.09		0.09		0.00
	4h	0.45		0.45		0.18
	24h	0.90		0.90		0.45
	48	0.90		0.90		0.90
	No incorporation	0.90		0.90		0.90

Table 5I: Exemplary partial NH_3 emission factors related to TAN for the spreading of slurry at various mean soil temperatures, German inventory (expressed as share of TAN, Döhler et al. 2002)

Type	**Incorporation after**	**Broad cast**				**Trailing hose**			
	h	5 °C	10 °C	15 °C	25 °C	5 °C	10 °C	15 °C	25 °C
		Bare soil			Stubbles	Bare soil			Stubbles
Cattle slurry									
	1	0.03	0.06	0.10	0.20	0.01	0.03	0.04	0.10
	4	0.10	0.18	0.26	0.65	0.06	0.10	0.15	0.35
	6	0.14	0.25	0.35	0.78	0.09	0.14	0.20	0.47
	12	0.22	0.32	0.43	0.85	0.15	0.22	0.30	0.70
	24	0.26	0.36	0.46	0.90	0.22	0.31	0.39	0.80
	48	0.30	0.40	0.50	0.90	0.26	0.36	0.46	0.90
Pig slurry									
	1	0.01	0.025	0.04	0.15	0.01	0,01	0.02	0.08
	4	0.04	0,06	0.09	0.37	0.02	0.04	0.06	0.19
	6	0.05	0.08	0.11	0.47	0.03	0.05	0.08	0.25
	12	0.08	0.12	0.16	0.60	0.045	0.08	0.11	0.37
	24	0.09	0.16	0.21	0.67	0.06	0.11	0.14	0.48
	48	0.10	0.20	0.25	0.70	0.07	0.14	0.18	0.55

REFERENCES

Döhler, H., Eurich-Menden, B., Dämmgen, U., Osterburg, B., Lüttich, M., Bergschmidt, A., Berg, W., Brunsch, R., 2002. BMVEL/UBA-Ammoniak-Emissionsinventar der deutschen Landwirtschaft und Minderungsszenarien bis zum Jahre 2010. Texte 05/02. Umweltbundesamt, Berlin.

Eidgenössische Forschungsanstalt für Agrarökologie und Landbau Zürich-Reckenholz, Institut für Umweltschutz und Landwirtschaft Liebefeld (eds.), 1997. Ammoniak-Emissionen in der Schweiz: Ausmass und technische Beurteilung des Reduktionspotentials. Schriftenreihe FAL 26. Eidgenössische Forschungsanstalt für Agrarökologie und Landbau, Zürich.

Menzi, H., Achermann, B. (eds), 2001. UN/ECE Ammonia Expert Group. Berne, 18-20 September 2000. Proceedings. Environmental Documentation No. 133. Air.. Swiss Agency for the Environment, Forest and Landscape (SAEFL), Bern

Poulsen, H.D., Kristensen, V.F. (eds), 1998. Standard Values for Farm Manure. A Revaluation of the Danish Standard Values concerning the Nitrogen, Phosphorus and Potassium Content of Manure. DIAS report 7 (1). Danish Institute of Agricultural Sciences, Tjele

Spanish Ministry of Agriculture, Fisheries and Food, Directorate-General for Agriculture (ed), 2001. Agricultural GHG emissions estimation methodology. Spanish Ministry of Agriculture, Fisheries and Food, Madrid.

Webb, J., 2001. Estimating the potential for ammonia emissions from livestock excreta and manures. Environ. Pollut. 111, 395-406.