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:	**100601** **100602** **100603** **100604**
SOURCE ACTIVITY TITLE:	**USE OF PESTICIDES AND LIMESTONE (in Agriculture)** ***Use of pesticides and limestone (CO_2 only)*** ***Agriculture*** ***Forestry*** ***Market gardening***
NOSE CODE:	**110.06.01** **110.06.02** **110.06.03**
NFR CODE:	**4 G** **5 D**

1 ACTIVITIES INCLUDED

This chapter considers the emission of carbon species resulting from the application of pesticides and limestone to agricultural soils and plants.

The emission is estimated from the agricultural use of pesticides and limestone and the respective emission factor. For pesticides, 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. For limestone, emissions from quarrying are being considered in SNAP codes 02 and 03. However, carbon dioxide originating from the production of quicklime is dealt with in SNAP 04 06 18 (Limestone and Dolomite Use). In principle, the amount of carbon dioxide released from the decomposition of $CaCO_3$ during the calcination of limestone which is later used to sweeten soils should be regarded as an agricultural.

This chapter is an extension of chapter ag100600 (EMEP/CORINAIR 2002), which replaced its earlier version (EMEP/CORINAIR 1999).

The chapter is comprised of the following subcodes

10 06 01	Use of pesticides and limestone (CO_2 only)
10 06 02	Agriculture
10 06 03	Forestry
10 06 04	Market gardening

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

For liming, calcium carbonate (lime) may be used as limestone, dolomite or quicklime; it may also be a constituent of mineral fertilizers, in particular of calcium ammonium nitrate.

The methodology applied for liming in agriculture is the same as for forestry and market gardening.

2 CONTRIBUTION TO TOTAL EMISSIONS

2.1 Use of pesticides

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.

2.2 Limestone

In central Europe, a small fraction of the overall emission of carbon dioxide may originate from soil sweetening in agriculture (Germany 2001: approx. 0.2 %).

3 GENERAL

3.1 Description

3.1.1 Pesticides

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 4.1 can be considered as first estimates, assuming that application takes place under normal field conditions (i.e. no soil injection), with a standard meteorology.

3.1.2 Carbon dioxide

Agricultural land use of soils other than calcareous soils will lead to a depletion of the soil buffer system which help to maintain a favourable range of pH. The most common and cheapest method to restore soil pH is liming.

As agricultural soils are limed regularly, all limestone, dolomite etc. can be considered to react according to

$$\mathrm{CaCO_3 + CO_2 + H_2O \rightarrow Ca^{2+} + 2\,HCO_3^{-} \rightarrow Ca^{2+} + 2\,OH^{-} + 2\,CO_2}$$

This long-term process cannot be influenced by other variables.

3.2 Controls

3.2.1 Pesticides

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.

3.2.2 Carbon dioxide

There is no method to avoid CO_2 emissions from liming.

4 SIMPLER METHODOLOGY

4.1 Pesticides

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 (see Table 4.1) as:

$$E_{\text{pest}} = \sum_{1}^{\text{i}} m_{\text{pest, i}} \cdot EF_{\text{pest, i}}$$

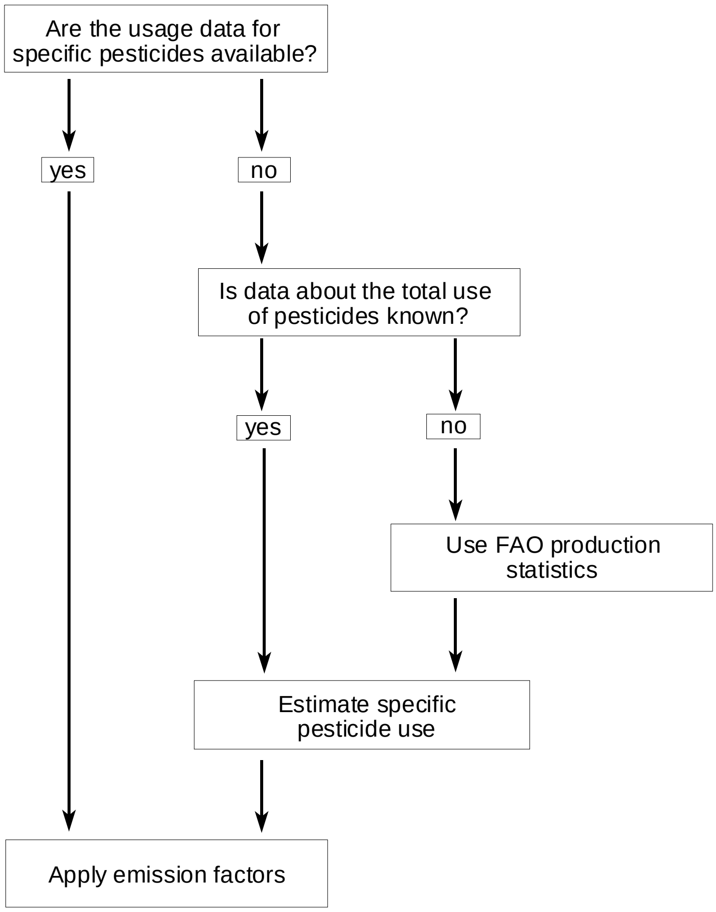
where E_{pest} total emission of pesticides (in Mg a^{-1})
m_{pest} mass of individual pesticide applied (Mg a^{-1})
EF_{pest} emission factor for individual pesticide (kg kg^{-1})

Table 4.1: 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
Heptachlor	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

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

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



Relevant activity statistics and emission factors are given in section 6. A list of common names of pesticides and their properties can be found under ISO (2003). Methods for estimating the use of pesticides are described below. The derivation of the emission factors is explained in Chapter 8.

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 gives a schematic overview of these three different methods.

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

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

- **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 a^{-1} (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 a^{-1} 0.05 = 25 t a^{-1}

  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.

- **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 (i.e. those listed in table 4.1) 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 country A?
  Lindane is used mainly in cereals. FAO production statistics for cereals in country A equals 12.626.000 Tg. In neighbouring country B 5.290.000 Tg of cereals was produced, and the use of Lindane equalled 25 t a^{-1}. So the Lindane use in country A is calculated to be (12.626.000 Tg/5.290.000 Tg) * 25 t a^{-1} = 60 t a^{-1}.

- **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.

4.2 Carbon dioxide

Carbon dioxide emissions from liming are calculated from the amount of lime, dolomite, quick lime and calcium ammonium nitrate using the relation

$$E_{\mathrm{lime}} = \sum_{1}^{\mathrm{i}} m_{\mathrm{lime,\,i}} \cdot EF_{\mathrm{lime,\,i}}$$

where E_{lime} total emission of C or CO_2 from liming (in Mg a^{-1})

m_{lime} mass of individual liming agent applied (Mg a^{-1})

EF_{lime} emission factor (carbon conversion factor) for individual liming agent (kg kg^{-1})

The individual emission factors (carbon conversion factors) are listed in Table 4.2.

Table 4.2: Simpler methodology emission factors for CO_2 emissions resulting from liming
Values are kg CO_2-C or CO_2 per kg liming agent applied.

Liminig agent	**CO_2-C**	**CO_2**
Lime ($CaCO_3$)	0.120	0.440
Dolomite ($CaMg(CO_2)_2$)	0.130	0.477
Calcium ammonium nitrate (CAN)	x · 0.120	x · 0.440
Quicklime (CaO)	0.214	0.785

where x denotes the proportion of calcium carbonate in calcium ammonium nitrate, which is normally 0.4.

5 DETAILED METHODOLOGY

Not available for pesticides. For liming, the simpler methodology cannot be improved.

6 RELEVANT ACTIVITY STATISTICS

Recent use of pesticides is not documented. For recalculations, Table 6.1 may be useful.

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

Country	**Insecticides Mg a^{-1}**	**Herbicides Mg a^{-1}**	**Available base year**
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.

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 coefficients or other parameters, but there are not enough data available to make a more reliable estimate of the emission factors.

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
Germany	4.6	0	-	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

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

The emission factors are derived from the vapour pressure according to Table 8.1.

Table 8.1: Derivation of emission factors from vapour pressures

Vapour pressure class	**Vapour pressure p mPa**	**Emission factor**
very high	$p > 10$	0.95
high	$1 < p < 10$	0.50
AVERAGE	$0.1 < p$ 1	0.15
low	$0.01 < p < 0.1$	0.05
very low	$p < 0.01$	0.01

Comparison of these factors with former emission factors made for OSPARCOM-HELCOM-UNECE (TNO-Report TNO-MEP-R 95/247) indicates that 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 are available, countries may calculate their emissions using both the ‘old data’ and the ‘new 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 EU) are derived by extrapolation or from few measurements.

Another 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.

For liming, the accuracy depends on the accuracy of the amounts of liming agents applied.

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.

For liming, disaggregation is not necessary due to the minor importance of the source and the atmospheric half-life of carbon dioxide.

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 (see http://apps.fao.org/page/collections?subset=agriculture)
OECD pesticide data (however, no recent data published)

16 VERIFICATION PROCEDURES

-

17 REFERENCES

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18 BIBLIOGRAPHY

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19 RELEASE VERSION, DATE AND SOURCE

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SNAP CODES :		
	10 09 01	**10 09 08**
	10 09 02	**10 09 09**
	10 09 03	**10 09 10**
	10 09 04	**10 09 11**
	10 09 05	**10 09 12**
	10 09 06	**10 09 13**
	10 09 07	**10 09 14**
		10 09 15

SOURCE ACTIVITY TITLE :	**MANURE MANAGEMENT REGARDING NITROGEN COMPOUNDS**	
	Dairy cows	***Broilers***
	Other cattle	***Other poultry***
	Fattening pigs	***Fur animals***
	Sows	***Goats***
	Sheep	***Mules and asses***
	Horses	***Camels***
	Laying hens	***Buffalo***
		Any other animals

NOSE CODES :		
	110.09.01	**110.09.08**
	110.09.02	**110.09.09**
	110.09.03	**110.09.10**
	110.09.04	**110.09.11**
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	110.09.06	**110.09.13**
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		110.09.15

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	4B1a	**4B5**
	4B1b	**4B6**
	4B2	**4B7**
	4B3	**4B8**
	4B4	**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 Nether-lands[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 management	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)

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

where

$N\mathrm{ex}_{\mathrm{(AWMS)}}$	nitrogen excretion rate per AWMS (kg a^{-1} N)
$n_{\mathrm{(T)}}$	number of animals of type T in the country
$N\mathrm{ex}_{\mathrm{(T)}}$	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..
$AWMS_{\mathrm{(T)}}$	fraction of $N\mathrm{ex}_{\mathrm{(T)}}$ 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.

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

$N_2O_{(\mathrm{AWMS})}$	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

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

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

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

where

$N\text{ex}_{\text{housing, (T)}}$	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 $N\text{ex}_{\text{housing (T)}}$ 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

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

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:

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

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.

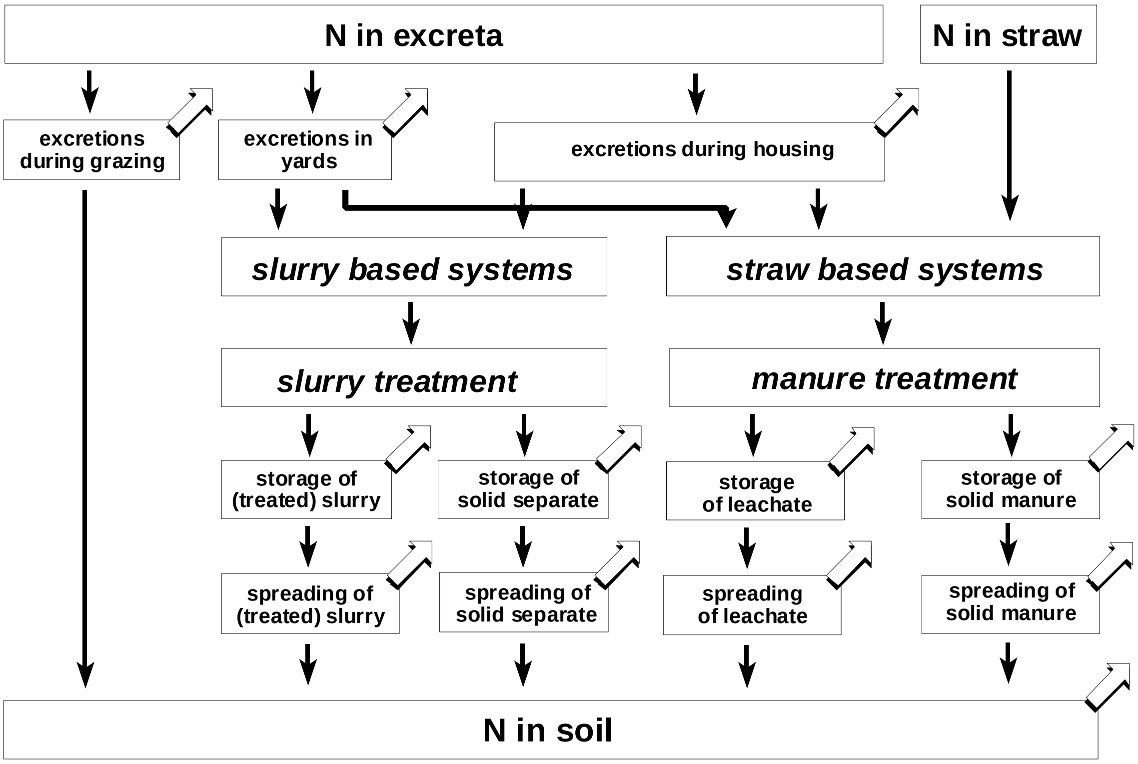
There are consequently several advantages over the simpler methodology:

- 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 Agriculture & Nature Expert Panel chair Ulrich Dämmgen, see section 20 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

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19 RELEASE VERSION, DATE AND SOURCE

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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.

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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]	Netherlands	UK [3]	Denmark [4]	Switzerland [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]	Nether-lands	UK [3]	Denmark [4]	Switzer-land [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

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SNAP CODES :	**101001** **101002** **101003** **101004** **101005** **101006** **101007** **101008** **101009** **etc.**
SOURCE ACTIVITY TITLE :	**PARTICLE EMISSIONS FROM ANIMAL HUSBANDRY** ***Dairy cattle*** ***Other cattle*** ***Fattening pigs*** ***Sows*** ***Horses*** ***Laying hens*** ***Broilers***
NOSE CODES:	**110.01.01** **110.01.02** **110.01.03** **110.01.04** **110.01.05**
NFR CODES :	**4G**

1 ACTIVITIES INCLUDED

This chapter deals with primary particle emissions from ventilated animal housing systems. Due to the lack of reliable data, emissions from free-range animals, the storage and application of solid and liquid animal manures are not yet included in this chapter.

2 CONTRIBUTIONS TO TOTAL EMISSIONS

Apart from industry, traffic and private households, the agricultural sector is a considerable contributor to emissions of particulate matter (PM). Agricultural activities such as plant and animal production on both farm sites and fields cause PM emissions. Although a reduction of PM emissions is observed for Europe, an increasing proportion of primary PM_{10} emissions originates from agriculture including emissions from animal housing (Tab. 2.1). An earlier estimate by Klimont and Amann (2002) showed also a similar trend, i.e., European emissions from animal housing representing 2.7 and 4.3 % of total PM_{10} in 1990 and 2000, respectively. Klimont and Amann (2002) estimated that the major source of PM emissions from housing are poultry and pig livestock operations, which are responsible for 57 % and 32 % of PM_{10}

emissions and 50 % and 30 % of $PM_{2.5}$ releases, respectively. More recent calculations (RAINS, 2005) suggest that each of the above sources contributes about 40 % of the total PM_{10} and between 35 and 45 % of $PM_{2.5}$ emissions from animal housing.

Table 2.1: Estimated emissions of PM_{10} and the relative contribution of emissions from animal housing in Europe between 1990 and 2000 (RAINS, 2005) (emissions in Gg a^{-1}, share of animal housing in %)

	1990	2000
Overall PM emissions	Gg a^{-1}	Gg a^{-1}
Europe	10827	5085
EU25	4577	2346
Non-EU*	6250	2739
Share of emissions from animal housing	%	%
Europe	2.8	5.2
EU25	3.5	6.5
Non-EU*	2.3	4.0

* Including European part of Russia

Based on the results of the RAINS model calculations, animal housing represents about 35 % of the total European PM_{10} emissions from agricultural operations, that is, including arable land, storage and handling of agricultural products, open burning of agricultural residues, and emissions from off-road machinery (tractors, harvesters, etc.).

3 GENERAL

3.1 Description

In contrast to many trace gases, particulate matter does not only have effects on the chemical composition and reactivity of the atmosphere but also affects human and animal health and welfare. When breathed in, a particle-loaded atmosphere impacts on the respiratory tract. The observable effects are dependent on the particle size, so it is necessary to define different size categories as a function of particle size. The most important regulated particle matter categories include TSP, PM_{10} and $PM_{2.5}$ (see Definitions in Appendix A).

There are several sources of the enrichment of air-borne particulate matter within livestock buildings. The feed itself and the feeding process may contribute to 80 to 90 % of the total dust generation. Bedding materials like straw or wood shavings can also have extraordinary effects on the particle concentration in the livestock air. Depending on the type and the amount of litter and its spreading, its contribution can be between 55 and 68 % of the total airborne particulates observed. The animal skin, fleece or plumage of housed animals and their faeces and urine cause dust emissions which may contribute up to 12 % of the total dust amounts released within livestock buildings. To a lesser extent, particles may originate from friction against floors, walls and other structural elements and from the air intake into the house.

Animal activity may also lead to re-suspension into the livestock house atmosphere of dust already settled (re-entrainment).

3.2 Definitions

3.2.1 Particulate matter

For a detailed set of definitions of terms related to PM emissions from agricultural sources see Appendix A.

3.2.2 Housing types

Forced ventilated building: a building in which ventilation is provided by electrically powered fans.

Litter: Bedding material to provide some comfort to the animals and to absorb moisture (e.g. straw, wood shavings).

Slatted floor: A floor with slots that allow faeces and urine to drop into a channel or pit beneath.

Cubicle house: A building that is divided into rows of stalls or cubicles where animals lie when at rest but where animals are not restrained.

Cages: A closed building with forced ventilation, in which the birds are kept in tiered cages.

Perchery: A house for laying hens with forced ventilation, where birds have freedom of movement over the entire house and a scratching area. It contains different functional areas for feeding and drinking, sleeping and resting, scratching, egg laying.

(terminology in accordance with Pain and Menzi, 2003)

3.3 Emissions

Emissions of particulate matter (PM) occur from both housed and free-range livestock animals. Because of the lack of available emission data for free-range animals, the definition of emission factors have focused on housed animals. The mass flows of emitted particles are governed on the following parameters (examples in brackets), thus causing uncertainties in terms of predicted emissions (Seedorf and Hartung 2001):

- physical density and particle size distribution of livestock dust.
- type of housed animals (poultry vs mammals).
- kind of feeding system (dry versus wet, automatic versus manual, feed storage conditions).
- kind of floor (partly or fully slatted).
- the use of bedding material (straw or wood shavings).
- the manure system (liquid vs solid, removal and storage, manure drying on conveyor belts).

- animal activity (species, circadian rhythms, young and adult animals, caged and aviary systems).
- ventilation rate (summer vs winter, forced and natural ventilated).
- geometry and positions of inlets and outlets (re-entrainment of deposited particles caused by turbulences above the surfaces within the animal house).
- indoor climate in the livestock (temperature and relative humidity).
- the time-period of housing (whole year vs seasonal housing, e.g. cattle).
- the management (all-in and all-out systems with periods of empty livestock building due to cleaning and disinfection procedures vs continuously rearing systems, e.g. pigs).
- secondary sources due to farmers' activities (tractors, walking through the building to check on livestock)

3.3 Controls

A range of processing techniques are available to reduce concentrations of air-borne dust in livestock buildings. Measures like wet feeding, fat additives to feed, manure drying via conveyor belt systems, oil and/or water sprinkling are some examples of indoor techniques preventing excessive dust generation. Apart from these measures, end-of-pipe technologies are also available to reduce PM emissions significantly, in particular filters, cyclones, electrostatic precipitators, wet scrubbers or biological waste air purification systems. However, most of these are either considered too expensive, technically unreliable or not user friendly to be widely adopted by agriculture.

When applicable abatement techniques become available, emission factors will be added in the methodology to calculate the PM_{10} emissions.

4 FIRST ESTIMATE

4.1 Emissions from housed animals

Particle emissions may be related to animal numbers or animal place numbers according to

$$E_{\mathrm{PM}} = \sum_{\mathrm{ij}} \mathrm{n}_{\mathrm{ij}} \cdot x_{\mathrm{t,i}} \cdot EF_{\mathrm{PM,ij}}$$

with E_{PM} emission of PM from animal husbandry (in kg a^{-1} PM)
n_{ij} number of animal places in an animal category i according to the census (in places) in a housing type j
$x_{\mathrm{t,I}}$ time fraction, during which animals of category i are housed (in a a^{-1})
$EF_{\mathrm{PM,ij}}$ emission factor for a given animal category i and housing type j (in kg place^{-1} a^{-1} PM)

For grazing periods, particle emissions from cattle, pigs, sheep and horses are considered to be negligible. The emissions are to be calculated assuming that the emissions are directly related to the time the animals are housed.

Table 4.1: First estimates of emission factors EF_{PM} for particle emissions from animal husbandry (housing) (for derivation see Appendix B)

Animal category	**Housing type**	**Emission factor for PM_{10} kg animal^{-1} a^{-1}**	**Emission factor for $PM_{2.5}$ kg animal^{-1} a^{-1}**
Dairy cattle	Tied or litter	0.36	0.23
	Cubicles (slurry)	0.70	0.45
Beef cattle	Solid	0.24	0.16
	Slurry	0.32	0.21
Calves	Solid	0.16	0.10
	Slurry	0.15	0.10
Sows	Solid	0.58	0.094
	Slurry	0.45	0.073
Weaners	Solid	n.a.	n.a.
	Slurry	0.18	0.029
Fattening pigs	Solid	0.50	0.081
	Slurry	0.42	0.069
Horses	Solid$^{1)}$	0.18	0.12
Laying hens	Cages	0.017	0.0021
	Perchery	0.084	0.0162
Broilers	Solid	0.052	0.0068

n.a.: not available
$^{1)}$ wood shavings

6 RELEVANT ACTIVITY STATISTICS

Information is required on animal numbers or animal places, respectively, and for the prevailing housing systems or their frequency distribution. For grazing animals, the duration of the grazing season and the daily grazing time are needed.

7 POINT SOURCE CRITERIA

Emissions from animal husbandry may originate from houses and from feed lots etc. Emissions from animal houses should be treated as point sources.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

not applicable at this stage of knowledge

9 SPECIES PROFILES

10 UNCERTAINTY ESTIMATES

No uncertainty can be given for this first estimate methodology.

The emission factors are a first estimate only. Further uncertainties may arise from estimates of grazing times.

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

The basis of the estimate is a limited number of measurements in north western Europe of inhalable and respirable dust emissions from animal houses with forced and free ventilation related to livestock units. The current emission factors have been transformed into PM emissions per animal per annum using poorly defined factors. Only the main animal categories have been dealt with.

There is obviously the need to perform measurements of PM fluxes for all respective important housing systems and animal categories in all countries using this Guidebook.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

Not relevant, as houses are considered to be point sources.

13 TEMPORAL DISAGGREGATION CRITERIA

Not relevant, as the data provided are annual means

14 ADDITIONAL COMMENTS

It is principally agreed that housing systems with litter (solid manure) are causing higher dust burdens than livestock buildings without litter (slurry), because bedding material such as straw consists of loose material, which becomes easily air-borne caused by mechanical agitations and therefore contribute to the overall indoor dust concentration considerably (Hinz et al., 2000). However, the contribution of the bedding material to airborne particles is contradictory to some extent. During winter for example, Takai et al. (1998) found in English dairy cow buildings with litter higher inhalable dust concentrations than in German cubicle houses with dairy cows, where slurry based systems were operated. Therefore, the calculated emission rates for particulate matters differed, too. Because the data from Takai and co-workers were taken for the first estimates here, the proposed emission factors in Table 4.1, A.1 and A.4 show a similar order for dairy and beef cattle.

Reasons for such deviations are due to the lack of sufficient information concerning quality and quantity of used bedding material (e.g. straw, chopped straw, wood shavings, sawdust, peat, sand, use of de-dusted bedding materials, mixtures of different materials, litter moisture, supplementation with de-moisturing agents, used mass of bedding material per animal), frequency of litter renewing (e.g. weekly vs. monthly), variations of animal density and its impact on dust liberating forces caused by the animal's activities or randomly high ventilation rates in cubicle houses resulting in relative higher emission rates in comparison to litter-based systems. In conclusion, more data need to be taken on emission rates of particulates in order to better determine both mean emission rates and variability of emission rates due to various environmental and management factors and is therefore also a target for prospective verification procedures.

15 SUPPLEMENTARY DOCUMENTS

16 VERIFICATION PROCEDURES

17 REFERENCES

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18 BIBLIOGRAPHY

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APPENDIX A

Particulate matter - definitions

Particulate matter (PM) is defined as particles of solid or liquid matter suspended in air. They are characterized by their origin (primary and secondary particles), their particle size, their composition and their potential physiological pathways.

Primary emissions are directly emitted by a source. Secondary particles are formed in the atmosphere by chemical reactions of certain gases that either condense or undergo chemical transformation to a species that condenses as a particle (Seinfeld, 1986). (The expression “secondary particle” is also sometimes used to describe redispersed or resuspended particles.)

To make particle size comparisons possible, the so-called aerodynamic diameter (d_{ae}) is used to standardize the expression of different particle sizes. The aerodynamic diameter (d_{ae}) is the diameter (in µm) of an idealized spherical particle of unit density (1 g cm^{-3}) which behaves aerodynamically in the same way as the particle in question (e.g. with regards to its terminal settling velocity). It is used to predict where particles of different size and density may be deposited in the respiratory tract. Particles having the same aerodynamic diameter may differ in dimension and shape. Due to the heterogeneity of particles the sampling characteristics of sampling devices have to be standardized. From that point of view the so-called collection efficiency (CE) is an important specification. The CE is usually expressed as the 50 % aerodynamic cut-off diameter (d_{50}). Such a d_{50} is generally assumed to be the size above which all particles larger than that size are collected to 50 % at least. The CE is usually determined using monodisperse particles. The cut-off curves may vary in sharpness and will depend on the type of sampler (Henningson and Ahlberg, 1994).

Total suspended particulate matter (TSP) refers to the entire range of ambient air matter that can be collected, from the sub-micron level up to 100 µm in d_{ae}. Particles with a d_{ae} larger than 100 µm will not remain in air for a significant length of time.

PM_{10} is the fraction of suspended particulate matter in the air with d_{ae} less than or equal to a nominal 10 µm, which are collected with 50 % efficiency by a PM_{10} sampling device. These particles are small enough to be breathable and could be deposited in lungs, which may cause deteriorated lung functions.

A further TSP-related size fraction is $PM_{2.5}$, which describes particles with an aerodynamic diameter d_{ae} less than or equal to nominal 2.5 µm and capable to be collected by measuring devices with 50 % collection efficiency. Exposure to considerable amounts of $PM_{2.5}$ can cause respiratory and circulatory complaints in sensitive individuals. $PM_{2.5}$ also causes reductions in visibility and solar radiation due to enhanced scattering of light.. Furthermore, aerosol precursors such as ammonia (the source of which is mainly agriculture) form $PM_{2.5}$ as secondary particles through chemical reactions in the atmosphere.

For toxicological purposes, further dust classifications have been introduced e.g. to characterise occupational settings. For this reason, the terms “inhalable dust”, “thoracic dust” and “respirable dust” were introduced.

To imitate the different breathable particle fractions (inhalable, thoracic, respirable) sampling criteria were defined by conventions, which define curves with the desired sampling performance of a sampler in terms of the fractional collection for particles up to 100 µm (CEN EN 481, Fig. 1). Therefore, the term inhalable dust is widely used to describe dust qualities that might be hazardous when deposited anywhere in the respiratory system, including the nose and mouth. It has a d_{50} of 100 µm and consequently includes the big and the small particles. Consequently, many dust emission data relate to 'inhalable dust' (e.g. Takai et al., 1998).

EPA describes inhalable dust as that size fraction of dust which enters the respiratory tract, but is mainly trapped in the nose, throat, and upper respiratory tract. The median aerodynamic diameter of this dust is about 10 µm.

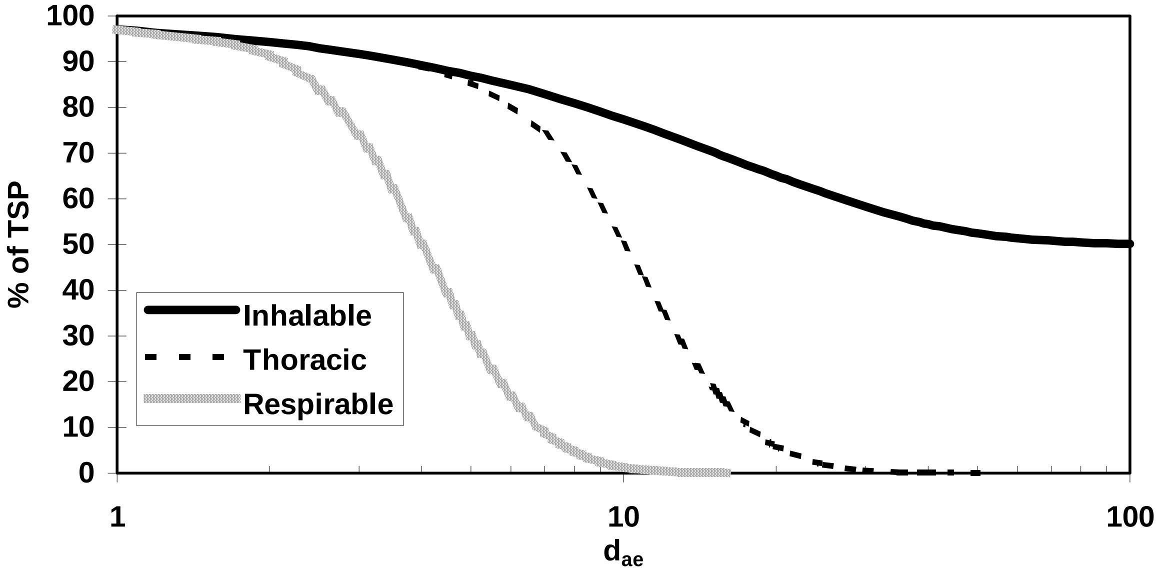

Fig. A1: Sampling criteria for inhalable, thoracic and respirable particles expressed as percentage of TSP.

According to Fig. A1 the thoracic dust fraction is related to a d_{50} of 10 µm indicating particles, which are mainly able to deposit in the airways of the lung (e.g. bronchi). The term "respirable dust" describes airborne particles, which are capable of invading the smaller airways and the alveoli of the lung, where the gas-exchange takes place. In the past, several definitions for respirable dust were proposed. Apart of definitions which specify respirable dust as particles with an aerodynamic diameters smaller than 7 µm, the Australian Standard AS 2985-1987 defines respirable dust as dust with a 50 % cut-off point of 5 µm. ACGIH (1998) defined respirable dust as having a 50 % cut-point of 3.5 µm. To reach world-wide consensus on the definition of respirable dust in the workplace, a compromise curve was developed with a 50 % cut-point of 4 µm. This standard definition is also implemented in CEN EN 481.

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APPENDIX B

Derivation of emission factors

Due to the lack of directly measured PM_{10} emissions, emission factors for PM_{10} from animal housing have to be derived from measurements of inhalable dust. Takai et al. (1998) summarized the experimental results obtained in a comprehensive study peformed in England, The Netherlands, Denmark and Germany in tables relating emissions of inhalable and respiratory particles from animal houses to livestock units. For horses, values obtained by Seedorf and Hartung (2001) serve as source. These data are listed in Table B1.

Transformations are needed to convert livestock units into animal numbers. In addition, inhalable and respirable dust concentrations have to be transformed into the respective PM concentrations. However, the resulting "correction factors" have to be used with care, because the representativeness of these factors is poorly understood. As a consequence, the methodology is considered a first estimate methodology rather than a simpler methodology.

Table B1: Measured dust emissions (all data except horses: Takai et al. 1998; horses: Seedorf and Hartung, 2001)

Animal category	Housing type	Emissions	
		ID mg LU^{-1} h^{-1}	RD mg LU^{-1} h^{-1}
Dairy cattle	Litter	89.3	28.0
	Cubicles	172.5	28.5
Beef cattle	Litter	85.5	16.0
	Slats	113.0	13.7
Calves	Litter	132.0	27.3
	Slats	127.5	19.5
Sows	Litter	448.5	47.5
	Slats	345.8	47.8
Weaners	Litter	n.a.	n.a.
	Slats	1021.0	75.5
fattening pigs	Litter	725.5	71.0
	Slats	612.3	66.0
Horses	Litter1)	55	n.a.
laying hens	Cages	636.3	78.3
	Perchery	3080.7	595.3
Broilers	Litter	3965.8	517.5

n.a.: not available; ID: inhalable dust; RD: respirable dust
1) wood shavings

In order to get mean emissions per animal head, means of these data have to be divided by the average weight of the animals in the respective category. Livestock unit (LU) is here defined as a unit used to compare or aggregate numbers of different species or categories and is equivalent to 500 kg live weight. A list of relevant LUs is given in Table B2.

Table B2: Conventional livestock units

	Weight kg animal^{-1}	Transfer factor LU animal^{-1}
Calves	50 to 100	0.1 to 0.5
Young cattle	450 to 650	0.6 to 1.2
Dairy cow	600 to 650	1.2
Horses		0.8 to 1.5
Boars		0.3
Sows		0.3
Fattening pigs		0.12
Piglets		0.01
Sheep		0.1
Laying hens		0.0031
Chicken		0.0015

The quantities of inhalable and respirable dust have to be transformed into quantities of PM_{10} and $PM_{2.5}$. Transformation factors for cattle are derived from a 24 hour PM monitoring survey that was made in a cubicle house with dairy cows and calves, housed on slatted floor and solid floor with straw. The one-day survey was conducted with an optical particle counter, which recorded the mass concentrations of total dust, PM_{10} and $PM_{2.5}$. The result of this investigation was used to calculate the conversion factor for PM_{10} (Seedorf and Hartung, 2001), while the conversion factor for $PM_{2.5}$ was determined later (Seedorf and Hartung, unpublished). The conversion factors for pigs were derived from Louhelainen et al. (1987). Horses were assumed to have a transformation factor similar to cattle. For poultry, this methodology makes the assumption that the concentration of inhalable dust is approximately the same as that of PM_{10}, and that the concentration of respirable dust may be considered to be of the same order of magnitude as that of $PM_{2.5}$. However, simultaneous measurements of inhalable dust and PM_{10} in a turkey barn have recently shown that the mean ratio between both dust fraction was lower than 1.0, namely approximately 0.6 (Schütz et al. 2004). Overall the real quantitative relationships between dust fractions have to be verified in future. Nevertheless, for a very first estimate some of these transformation factors are compiled in Table B3.

Table B3: Transformation factors for the conversion of inhalable dust (ID) and respirable dust (RD) into PM_{10} and $PM_{2.5}$

Animal type	Transformation factor for PM_{10} kg PM_{10} (kg ID)$^{-1}$	Transformation factor for $PM_{2.5}$ kg $PM_{2.5}$ (kg ID)$^{-1}$
Dairy cows(101001)	0.46 $^{1)}$	0.30 $^{2)}$
Other cattles (101002)	0.46 $^{1)}$	0.30 $^{2)}$
Fattening pigs(101003) (including weaners)	0.45	0.08
Sows (101004)	0.45	0.08
Horses$^{)3}$ (101006)	0.46 $^{1)}$	0.30 $^{2)}$
	kg PM_{10} (kg ID)$^{-1}$	kg $PM_{2.5}$ (kg RD)$^{-1}$
Poultry	1.0	1.0

1) Seedorf and Hartung (2001), the same conversion factor for horses is assumed as for cattle

2) Seedorf (2001) unpublished

The resulting emission factors in kg animal^{-1} a^{-1} are listed in Table B4.

Table B4: Emission factors for inhalable dust, respirable dust, PM_{10} and $PM_{2.5}$

Animal category	Housing type	Animal weight	Conversion factor	Emission factors *EF*			
				ID	RD	PM_{10}	$PM_{2.5}$
		kg animal^{-1}	LU animal^{-1}	kg animal^{-1} a^{-1}	kg animal^{-1} a^{-1}	kg animal^{-1} a^{-1}	kg animal^{-1} a^{-1}
Dairy cattle	Litter	500	1.0	0.78	0.25	0.36	0.23
	Cubicles	500	1.0	1.51	0.25	0.70	0.45
Beef cattle	Litter	350	0.7	0.52	0.10	0.24	0.16
	Slats	350	0.7	0.69	0.084	0.32	0.21
Calves	Litter	150	0.3	0.35	0.072	0.16	0.10
	Slats	150	0.3	0.34	0.051	0.15	0.10
Sows	Litter	150	0.3	1.18	0.12	0.58	0.094
	Slats	150	0.3	0.91	0.13	0.45	0.073
Weaners	Litter	20	0.04	n.a.	n.a.	n.a.	n.a.
	Slats	20	0.04	0.36	0.026	0.18	0.029
Fattening pigs	Litter	80	0.16	1.02	0.10	0.50	0.081
	Slats	80	0.16	0.86	0.093	0.42	0.069
Horses	Litter [1]	400	0.8	0.39	n.a.	0.18	0.12
Laying hens	Cages	1.55	0.0031	0.017	0.0021	0.017	0.0021
	Perchery	1.55	0.0031	0.084	0.0162	0.084	0.0162
Broilers	Litter	0.75	0.0015	0.052	0.0068	0.052	0.0068

n.a. not available
[1] wood shavings

The emission factors EF_{PM10} and $EF_{PM2.5}$ given in Table B4 are mainly of a similar order of magnitude as those used in the RAINS model for livestock operation (Klimont et al., 2002) (see Table B5). However, for cattle there is an obvious deviation in case of $EF_{PM2.5,}$ which might be caused by different detection methods used for $PM_{2.5}$ measurements (e.g. optical related measurements versus non-inertial sampling methods). Therefore, the proposed $EF_{PM2.5}$ for cattle and horses in Table B4 should in particular be used with care.

Table B5: PM_{10} emission factors EF_{PM10} as used in the RAINS model (Klimont et al. 2002)

Animal type	EF_{PM10} kg animal^{-1} a^{-1}	$EF_{PM2.5}$ kg animal^{-1} a^{-1}
Poultry	0.0473	0.0105
Pigs	0.4376	0.0778
Dairy cattle	0.4336	0.0964
Other cattle	0.4336	0.0964
Other animals [1]	n.a.	n.a.

[1] sheep, horses and fur animals
n.a.: not available

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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.

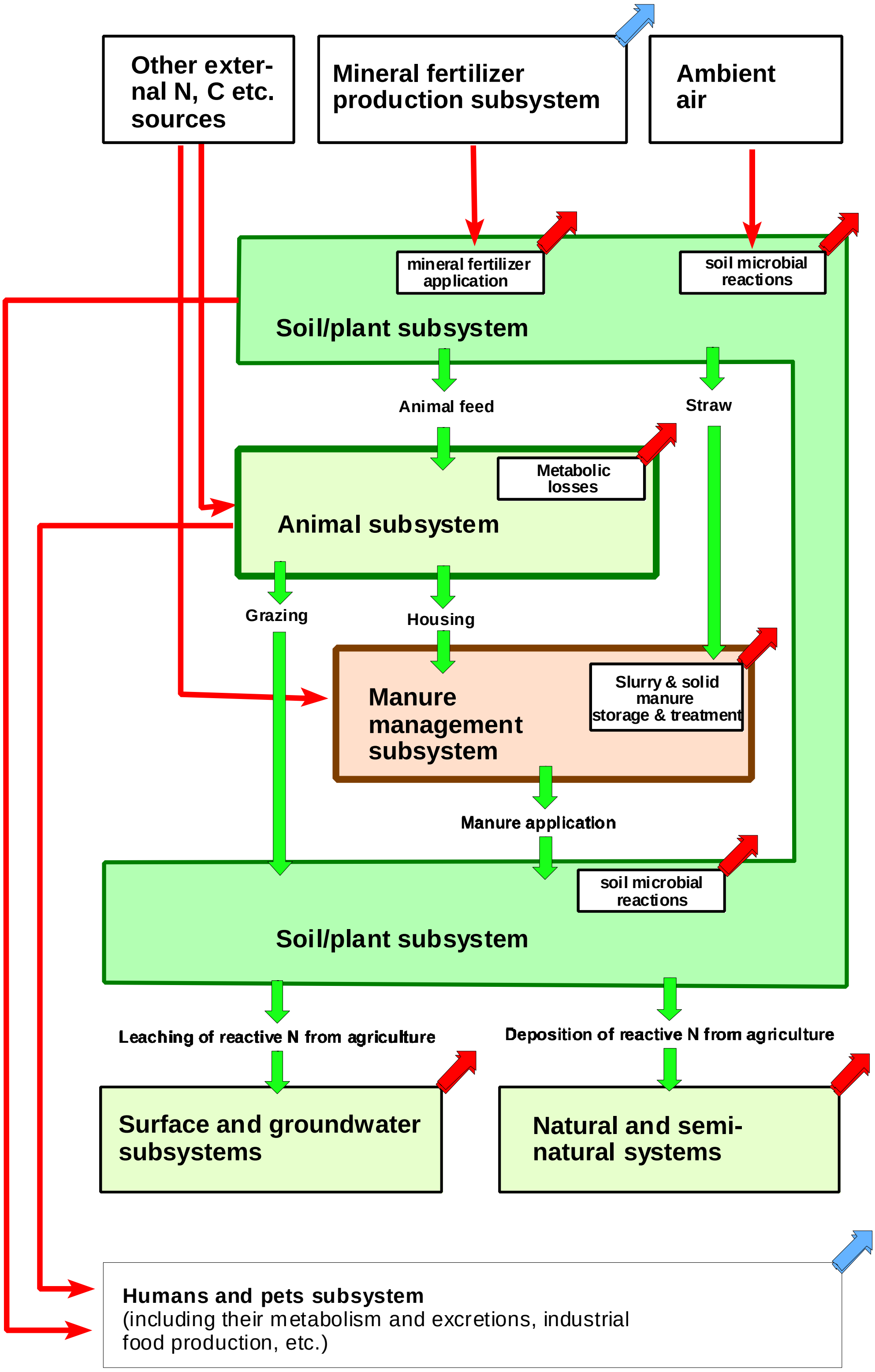

Fig. 1: Mass flows considered in the EMEP/CORINAIR Guidebook Chapter 10 (Agriculture): Red arrows: mass flow between external sources and sinks and the agricultural subsystems; broad red arrows: emissions to the atmosphere. Green arrows: fluxes between agricultural subsystems. Blue arrows: emissions not accounted for as agricultural emissions (Dämmgen et al., 2003)

In principle, **CO_2 emissions** from agricultural processes due to soil, plant and animal breathing are not covered by this Guidebook section, as the combination of photosynthesis and breathing in agriculture and the humans and pets subsystem are balancing one another; and agriculture is considered neither a net source or sink. CO_2 released from the application of lime is considered an agricultural emission. By definition, only the non-energy processes and breeding are covered in section 10. CO_2 emitting processes that relate to agriculture such as fertilizer production are dealt with in other sections (see below).

Guidebook chapters in section 10 deal with emissions from the agricultural production system as a function of the fluxes outlined in Fig. 1:

Chapters 1 and 2 describe emissions from the plant production subsystem. The productivity of this system and the amount of gases emitted are a function of fertilizer input from external (mineral fertilizer) and internal sources (manure application). Emissions resulting from the input of lime and pesticides are quantified in chapter 6. Emissions from burning of organic material on the field site is subject of chapter 3.

Chapter 4 describes losses in the animal subsystem. It contains the emissions from metabolic processes within animals, in particular from enteric fermentation.

Chapters 5 and 9 depict manure management processes including losses from animal excreta in houses, during storage and spreading.

However, the treatment of agricultural emissions within Guidebook section 10 is somewhat inconsistent, as some emissions are dealt with independent of the structure provided in Fig. 1. Tables 1 to 4 are to give an overview. Herein, emissions of gases (Tables 1 to 3) and particles (Table 4) from various categories **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 present 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. In some cases, hints to establish a first estimate ("**FE**") are provided.

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	CO_2	NM VOC	PM	Remarks
Cultures with Fertilizers (Fertilized Agricultural Land)	Emissions from fertilizer N applied	10 01 00	**S, D**	**S, I**	**S, I**	**x**		**FE**		(1)
	Grazed grassland	10 01 00	**S**							
	Rice fields	10 01 00	**D**			**x**				(2)
	Organic soils	10 01 00		**S**			**x**			(3)

(1) CH_4: A method to quantify CH_4 consumption is given.
(2) CH_4: A hint towards the IPCC methodology is given.
(3) CO_2: A method to estimate the order of magnitude of emissions is proposed.

Table 1 (continued): 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	CO_2	NM VOC	PM	Re-marks
Cultures without Fertilizers	Legumes	10 02 00	**S, D**							
	Unfertilized grassland	10 02 00	**S**							
	Unfertilized agricultural soils	10 02 00		**S**	**S**					
	Indirect emissions due to deposition of reactive nitrogen species	10 02 00		**S**	**S**					
	Indirect emissions due to leaching and run-off of reactive nitrogen species	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**	**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 metabolic processes***

Category	Activity	SNAP	NH_3	N_2O	NO	CH_4	NM VOC	PM	Re-marks
Methane emissions from animal husbandry (Enteric fermentation)	Dairy cows	10 04 01				**S**			(1)
	Other cattle	10 04 02				**S**			
	Sheep	10 04 03				**S**			
	Fattening pigs	10 04 04				**S**			
	Horses	10 04 05				**S**			
	Mules and asses	10 04 06				**S**			
	Goats	10 04 07				**S**			
	Laying hens	10 04 08							
	Broilers	10 04 09							
	Other poultry	10 04 10							
	Fur animals	10 04 11							
	Sows	10 04 12				**S**			
	Camels	10 04 13							
	Buffalo	10 04 14							
	Any other animals	10 04 15							

(1) In previous Guidebook editions, chapter 10 04 dealt with CH_4 emissions both from enteric fermentation and from manure storage.

Table 3: Classification of activities according to EMEP/CORINAIR (2001) and attribution to SNAP 97 (2001): ***gases from manure management***

Category	Activity	SNAP	NH_3	N_2O	NO	CH_4	NM VOC	PM	Remarks
Manure management Regarding Organic Compounds	Dairy cows	10 05 01				**S, D**	**FE**		(1)
	Other cattle	10 05 02				**S, D**	**FE**		
	Fattening pigs	10 05 03				**S, D**	**FE**		
	Sows	10 05 04				**S, D**	**FE**		
	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							
	Goats	10 05 11				**S**			
	Mules and asses	10 05 12							
	Camels	10 05 13							
	Buffalo	10 05 14							
	Any other animals	10 05 11							
Manure management Regarding Nitrogen Compounds	Dairy cows	10 09 01	**S, I, D**	**S**	**S**				(2, 3)
	Other cattle	10 09 02	**S, I, D**	**S**	**S**				
	Fattening pigs	10 09 03	**S, I, D**	**S**	**S**				
	Sows	10 09 04	**S, D**	**S**	**S**				
	Sheep	10 09 05	**S, D**	**S**	**S**				
	Horses	10 09 06	**S, D**	**S**	**S**				
	Laying hens	10 09 07	**S**	**S**	**S**				
	Broilers	10 09 08	**S, D**	**S**	**S**				
	Other poultry	10 09 09	**S, D**	**S**	**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) Organic compounds include CH_4 and NMVOC. For the detailed methodology see Tier 2 in IPCC (1997, 2999).

(2) A method is considered *detailed* if it follows the pathway of N in detail. If it makes use of combined partial emission factors only, it is called *improved*.

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

Table 4: 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 Fertilizers) and 10 02 (Cultures without Fertilizers)

Subgroups 10 01 and 10 02 are to be assigned to all emissions (except those of CO_2) originating from 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 fertilization is taken into account whilst for subgroup 10.01 both intentional as well as unintentional fertilization are considered, each of these two categories being specified as follows:

Intentional fertilization comprises:

- Synthetic (mineral) fertilizer;
- Natural inorganic fertilizer;
- 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 SNAP 10 90.

Unintentional fertilization 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) fertilization are calculated and reported under indirect emissions in SNAP10 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 estimated.

NMVOC emissions occur both in fertilized and unfertilized systems. In this Guidebook, algorithms to estimate them are given in SNAPs 10 01 and 11 04 (Other Sources and Sinks) together with emissions from natural vegetation. However, they have to be reported under Cultures with Fertilizers (SNAP 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)

So far, the calculation of CH_4 emissions due to enteric fermentation follow the Tier 1 approach of the IPCC Guidelines. Reference is made to the respective Tier 2 approaches of the IPCC Guidelines.

In previous editions of the Guidebook, SNAP 1040 included the treatment of CH4 emissions from manure management.

3.4 10 05 and 10 09 (Manure Management Regarding Organic and Nitrogen Compounds)

The subgroups deal with emissions of all gaseous carbon nitrogen species (NH_3, N_2O, NO) from animal husbandry as a whole following the mass flow approach.

For CH_4, the IPCC Tier 1 and Tier 2 methodologies are taken over.

A tool to estimate the order of magnitude of NMVOC emissions from stored manure is provided.

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 fertilizer). Note that grazing of “hill sheep” would have to be reported under 10 02 (Cultures without fertilizer), but (at present) the emission factor is zero. Direct NH_3 emissions from manure and slurry applied to soil and plant canopies are to be reported under 10 09, whereas indirect emissions of N_2O and NO resulting from these NH_3 emissions have to be reported under 10 02 (Cultures without fertilizers).

3.5 Subgroup 10 06 (Use of Pesticides and Limestone)

At present, a simpler methodology is given for the assessment of emissions from the application of limestone and pesticides. For limestone, this is at the same time the best available approach.

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 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 Off-road Transport

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.

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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.

4.3 Open Burning of Agricultural Wastes (Except Stubble Burning)

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

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7 RELEASE VERSION, DATE AND SOURCE

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SNAP CODES :	**100101** **100102** **100103** **100104** **100105**
SOURCE ACTIVITY TITLE :	**CULTURES WITH FERTILIZERS** **(Fertilized Agricultural Land)** ***Permanent corps*** ***Arable land crops*** ***Rice fields*** ***Market gardening*** ***Grassland***
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1 ACTIVITIES INCLUDED

This chapter considers the emissions of ammonia (NH_3), nitrous oxide (N_2O), other oxides of nitrogen (NO_x), carbon dioxide (CO_2), methane (CH_4), and non-methane volatile organic compounds (NMVOCs) from agricultural soils to which nitrogen (N)-containing fertilizers are applied. For NH_3, emissions following application of animal manures to land are considered in SNAP code 100900, Manure Management Regarding Nitrogen Compounds. Although losses of NH_3 from N-fertilizers applied to grass grazed by livestock are difficult to distinguish from subsequent NH_3 emissions from urine patches produced by grazing animals, emissions are calculated separately; the calculation results are then compiled in this chapter. Ammonia emissions from grazed grassland due to decomposition of animal excreta applied to land are calculated in SNAP Code 100900, nitrous oxide losses after application are covered in this chapter. Persistent Organic Pollutants are dealt with separately under SNAP code 100600, Use of Pesticides.

This chapter is a development of chapter ag100100 (EMEP/CORINAIR 1999), which replaced its earlier version (EEA 1996).

The chapter is comprised of the following sub-codes

100101	Permanent crops
100102	Arable land crops
100103	Rice fields
100104	Market gardening

100105 Grassland

Sub-code 100106, Fallows, is not included, as N-fertilizer 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. Also separate emission factors are used for CH_4 in 100103 versus the other land use categories.

2 CONTRIBUTIONS TO TOTAL EMISSIONS

Fertilized agricultural land typically contributes approximately one tenth of the total source strength for European emissions of NH_3 (ECETOC, 1994; Bouwmann *et al.*, 1997) and NO (Skiba *et al.*, 1997), more than one third of N_2O (Mosier *et al.*, 1998), and about 1 % of CO_2 (Freibauer 2002). On national level, the contribution varies widely among EU member states. Emissions of gaseous N species from fertilized agricultural land are generally related closely to the amount and, in some cases, the type of fertilizer-N applied.

The major source of NH_3 in Europe is volatilization from livestock excreta. 10 - 20 % of agricultural NH_3 emissions have been estimated to derive from the volatilization of N-fertilizers and from fertilized crops (Asman, 1992; ECETOC, 1994). This range may be compared with the estimate of the CORINAIR 94 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 numbers. The non-agricultural sources make only a marginal contribution to the total emission of NH_3 (Sutton *et al.*, 2000).

Table 2.1: Relative contribution of cultures with fertilizers to total emissions in EU15 and accession states *(25 countries)* **in 1995 (in %)**

Source-activity						
SNAP-code 100100	NO_x	NMVOC	CH_4	CO_2	N_2O	NH_3
Cultures with Fertilizers	4.0	0.4	0.2	1.2	30	5.3
Reference	Freibauer 2002, extended	ETCAE, 1997	Freibauer 2002, extended	Freibauer 2002, extended	Freibauer 2002, extended	ETCAE, 1997

Freibauer (2002) estimated that, via soil processes, fertilizers and crops contributed *c.* 42 % of N_2O emissions on a European scale, including application of animal manures (30 % of total nitrogen fertilizer applied). Soils and crops are considered to be a net sink for most NO_x ($NO + NO_2$) compounds. However, NO may be released from soils during nitrification and denitrification following N application and mineralisation of incorporated crop residues and soil organic matter. Estimates of NO emissions are very uncertain, but soils may contribute c. 4 - 8 % of total European emissions. On a hot summer day this fraction may increase to values > 27 % (Stohl *et al.*, 1996, Butterbach-Bahl *et al.*, 2002).

A net carbon dioxide flux from agriculture (not regarding tractors and other machinery (see SNAP 0806, Other Mobile Sources, Agriculture) originates from land use changes and from the degradation of soil organic matter. The latter is of particular importance when organic soils are used as croplands.

In agriculture, methane is produced by anaerobic bacterial fermentation of organic matter in the presence of water. The three major sources are enteric fermentation (see SNAP 100400), manure management (see SNAP 100500) and wet rice production. Well aerated agricultural soils are a minor sink for methane, which is oxidized by methanotrophic bacteria. A mean consumption rate of about 0.5 kg ha^{-1} a^{-1} CH_4 can be assumed for well aerated European agricultural soils (Freibauer, 2002). Even for countries with a low fraction of the surface covered with rice fields or wetlands – which are strong sources for atmospheric CH_4 –, agricultural soils can be a net sink for methane (Roger *et al.*, 1999).

NMVOCs from this SNAP Code represent < 1 % of current total emission estimates, and do not therefore require a methodology for calculation yet. However, given current uncertainties over the magnitude of NMVOC emissions from agricultural crops, some information is given in this chapter, in order to provide background information and a tool to estimate the order of magnitude of these emissions as well as to highlight current uncertainties.

3 GENERAL

3.1 Description

3.1.1 Ammonia

The best information on NH_3 emissions from cultures with fertilizers concerns the direct emissions following fertilizer-N application. The evidence for direct emissions from, and uptake by, plant foliage is also good (Schjørring and Mattsson, 2001), though estimates of net emissions are much more uncertain. Although estimates of the component emissions from crop foliage have been made (Denmead *et al.*, 1983; Nemitz *et al.*, 2000), it is often difficult to separate the direct fertilizer and plant emissions in practice, since both are a function of fertilizer-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), Sutton *et al.* (1995b) and Schjørring and Mattsson (2001).

Emissions of NH_3 from mineral fertilizers depend on the type of N-fertilizer applied, soil type (especially soil pH), meteorological conditions and time of application in relation to crop canopy development (Holtan-Hartwig and Bøckmann, 1994; Génermont, 1996). In particular, the type of N-fertilizer applied has a great effect on the magnitude of emissions (Whitehead and Raistrick, 1990; ECETOC, 1994). Emissions are largest from urea fertilizer because urea hydrolysis in the soil releases CO_2, which creates a pH increase and favours NH_3 volatilization. These emissions can be reduced significantly by use of urease and nitrification inhibitors (e.g. Gioacchini *et al.*, 2001, and literature cited therein). Emissions from ammonium sulphate (AS) may also be large, but these are very dependent on soil pH, with larger emissions from calcareous soils. Other fertilizers, 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. Fertilizers containing only nitrate (NO_3^-) will not emit NH_3 directly, but may increase NH_3 emissions by the crop foliage.

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 fertilizer emissions as a single emission factor. The time scale over which the emission estimates are made is important to note. Fertilizer emissions are largest in the days after fertilizer application, but in some instances (e.g. urea applied in dry conditions resulting in a slow hydrolysis), fertilizer emission may proceed for over a month after application (Sutton *et al.*, 1995a). For background emissions (other than initial fertilizer 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; Schjørring and Mattsson, 2001). Foliar emissions are expected to be larger from annual cereal crops than from fertilized 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 fertilizer-N application (Jarvis *et al.*, 1989; Bussink, 1992). Moreover the proportion of NH_3 emitted increases with increasing fertilizer-N.

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

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-fertilizer 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, especially after cutting (Sutton *et al.*, 2000; Husted *et al.*, 2000).

3.1.2 Nitrous Oxide

In soil, N_2O is produced predominantly by two microbial processes, nitrification, i.e. the oxidation of ammonium (NH_4^+) to nitrate (NO_3^-) and denitrification, i.e. 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. Granli and Bøckman, 1994; Bouwman, 1996) and on the microbial characteristics of the soil, some soils promoting denitrification until N_2 and some other producing a large fraction of N_2O (Hénault *et al.*, 1998). Maximum N_2O emissions are generally observed within 2 to 3 weeks of N-fertilizer application. The magnitude of the emissions depend on the rate and form of fertilizer applied, the crop type and the soil temperature and soil moisture content. Application of N-fertilizer 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). Repeated changes in soil moisture status and re-wetting of dry soil promote episodic high N_2O emission rates (Flessa *et al.*, 1995). 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.

At the present stage of knowledge, too few data are available to derive emission factors for different fertilizers or soil types from existing data (Bouwman, 1996; Hénault *et al.*, 1998). In contrast, different emission factors have been estimated according to the type of crop in Scotland (Skiba *et al.*, 1997; Dobbie *et al.*, 1999), with larger emission factor for grassland, sugar beet, potato and horticultural crops and smaller for cereals. However, this has not yet been confirmed under different conditions and cannot be included in the general methodology at the present stage. Therefore, the IPCC method (IPCC/OECD, 1997) defines one single method for all types of N input and all crops. Furthermore, it must be taken into account, that annual emissions may vary significantly between different years due to differences in weather conditions, as was shown e.g. for a grassland site in the UK were annual emissions varied over 20-fold over 8 years (Smith and Dobbie, 2002).

Following the IPCC Methodology (IPCC/OECD 1997), N_2O emissions from agricultural soils may be calculated as the sum of direct soil emission following N inputs to agricultural fields, either from mineral or organic sources, direct emissions from cultivation of histosols, direct emission from excreta deposition of grazing animals and indirect emission following atmospheric deposition of NH_3 and NO_x in natural ecosystems like e.g. forests or leaching and runoff.

Emissions from animal waste management and manure spreading are included in SNAP Code 100900, Manure Management.

Direct emissions from cultures with fertilizers include emissions which are induced by N input (mineral and organic fertilizer, excretal N deposited during grazing, biological N fixation and crop residues). Emissions from plants have been observed (Gründmann *et al.*, 1993) but they are considered as marginal. 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. These soil and environmental factors also influence the magnitude of indirect N_2O emissions following atmospheric deposition of NH_3 and NO_x. The magnitude of the so called indirect emissions from e.g. forest ecosystems, is significant, since – due to chronically high atmospheric N-deposition – most forest ecosystems in Central Europe are N-saturated and have been shown to emit N_2O in a range of 0.2 – 5.0 kg N_2O-N ha^{-1} a^{-1} (Brumme and Beese, 1992; Butterbach-Bahl *et al.*, 1997a, 2001; Papen and Butterbach-Bahl, 1999).

3.1.3 Nitric Oxide

Nitric oxide (NO) is also a substrate and product of denitrification, but it is only very rarely as a consequence of denitrification in European soils. In cultures with fertilizers, where pH is likely to be maintained above 5.0, nitrification is considered to be the dominant pathway of NO emission (Remde and Conrad 1991; Skiba *et al.* 1997). Recent estimates consider that NO_x emission from soils could represent more than 40 % of NO_x emission at global scale (Davidson and Kingerlee, 1997; IGAC, 2000) and more than 10% for some European countries (Skiba *et al.*, 1997; Stohl *et al.*, 1996, Butterbach-Bahl *et al.*, 2002). Emissions resulting from fertilizer use could represent 40 % of soils emissions at global scale (IGAC, 2000) and up to 65 % for USA (Hall *et al.*, 1996).

The main determinants of NO production in agricultural soils are mineral N concentration (Skiba *et al.*, 1997), temperature and soil moisture (Yamulki *et al.*, 1995; Williams *et al.*, 1992). This is increased by N-fertilizer application, excretal N deposited during grazing, crop residue incorporation and cultivation.

Activities such as tillage and incorporation were considered to increase NO emissions by a factor of 2 to 7 (Skiba *et al.*, 1997, 2002). 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. The magnitude of indirect emissions of NO from soils of natural ecosystems like forests can be very high due to increased atmospheric N-deposition. Gasche and Papen (1999) showed, that NO-emissions from a spruce forest site in Bavaria were in a range of 5 - 7 kg NO-N ha^{-1} a^{-1}. Using a process-oriented model for regionalization Butterbach-Bahl *et al.* (2001) calculated that on annual basis NO-emissions from forest soils of Bavaria contributed less than 2 % to the total regional NO_x burden, whereas this figure was less than 8 % during summer.

3.1.4 Carbon Dioxide

Land use change leads to changes in the carbon stocks in vegetation and soil. The quantification of these changes requires long-term studies on carbon budgets and long term documentation of the kind of land use changes. The change from high soil organic carbon (SOC) to low SOC is a process that is faster by factor 5 than the sequestration process taking place when a soil accumulates carbon. Improved land management (for example measures that aim at carbon sequestration) can increase SOC. Here it is important to realise that increase of the soil organic carbon level (C-sequestration) takes a period of 50 - 100 a. Decrease in SOC (decomposition) due to any disturbance of the soil will take place within 10 a.

According to the IPCC Methodology (IPCC/OECD 1997), at minimum, the following processes of land use change have to be considered for cultures with fertilizers:

- conversion of woodland to grassland and cropland [1],
- conversion of grassland to cropland and *vice versa*, and

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[1] Woodland has a complete or near-complete canopy, whereas forests are considered to be fairly open areas with some trees, but also grassland and heath land.

- other land use change activities. These include the drainage of wetlands and cultivation of organic soils. Such activities represent a significant source of CO_2 in many, especially in Northern European countries. Since no default methodology was recommended, these emissions are rarely reported in national inventories although this neglect can lead to an underestimation of national emissions of CO_2-equivalents by up to 10 % (Kasimir Klemedtsson *et al.*, 1997).

The oxidation of peat in drained organic soils also occurs on histosols that have been under cultivation for many years. Subsidence associated with the loss of organic matter leads to a further drainage of the soil, which in turn enhances peat oxidation. The IPCC Methodology considers N_2O emissions on histosols (section 3.1.2) in the agriculture chapter, but addresses the concomitant CO_2 release in the chapter on land use change and forestry.

The management of agricultural land also affects its carbon balance through tillage, crop residues and organic amendments, which can lead to either CO_2 removals or release.

3.1.5 Methane

Both methanogenesis and CH_4 oxidation occur both sequentially and concurrently in soils. Heavy wetting or flooding cuts off the soil's oxygen supply, which may lead to anaerobic fermentation of organic matter and concomitant CH_4 formation. As CH_4 is produced by strictly anaerobic *Archaea*, CH_4 production can take place in micro-habitats only, where oxygen diffusion is inhibited by high water content, and where all oxygen and other electron acceptors (such as the oxides of iron and sulfur) have already been consumed by other bacterial processes. The last step in carbon degradation in soils is CH_4 production from the substrates acetic acid or the gases CO_2 and H_2. On the other hand, most of the methanotrophic bacteria (which belong to the *Eubacteria*) are limited to oxygen-rich environments. But soils which consume CH_4 more efficiently are those in which methanogenic conditions have occured (see e.g. Roger *et al.*, 1999). Emission data of CH_4 from soils with heterogenic water saturation, in space or in time, are therefore always mixtures of the two components stated above: anaerobic CH_4 production and aerobic CH_4 consumption (Conrad, 1996).

Fertilized and cultivated soils consume CH_4 at rates of 40 % or less of those in undisturbed forest soils as a result of complex short-term and long-term adverse effects of soil disturbance, shift in microbial species diversity and ammonium inhibition of methanotrophic activity (Hütsch, 2001).

3.1.6 Non-Methane Volatile Organic Compounds

Volatile Organic Compounds (VOCs) are all organic hydrocarbons and their derivatives. It has been customary to differentiate between methane and non-methane volatile organic compounds (NMVOCs). VOCs can produce photochemical oxidants and secondary particles, in particular by reaction with nitrogen oxides.

Three categories of sources may be distinguished:

- activities that emit NMVOCs by combustion or evaporation;
- land clearing, including burning;
- biogenic processes.

The primary sources in the agricultural sector are:

- burning stubble and other plant wastes;
- the use of organic solvents in pesticide production;
- anaerobic degradation of livestock feed and animal excreta.
- biogenic emissions of oxygenated VOCs

These 4 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) and emissions from pesticides in SNAP Code 100600. Emissions from livestock manure are included in SNAP Code 100500, Manure Management Regarding Carbon Compounds.

The emission of some NMVOCs 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 NMVOCs include temperature and light intensity, plant growth stage, water stress, air pollution and senescence (Hewitt and Street 1992). Emissions of NMVOCs 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. Although NMVOCs emissions from cultures with fertilizers are smaller than from forests, they may not be entirely negligible (Simpson, 1999).

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.

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.

Fertilized agricultural grassland. Grassland, to be used for either cutting grass or conservation, grazing or both, to which synthetic N-fertilizers 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 (including emission from the applied fertilizer and from the plant *via* stomata) 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-fertilizers. Urea has been considered to contribute approximately 50 % of the fertilizer emissions in western Europe (ECETOC, 1994) because of its wide use and greater NH_3 volatilization rate. A potentially effective control of fertilizer emissions would, therefore, be to use alternative N-fertilizers with smaller NH_3 emissions. A further possibility is to add urease regulators/inhibitors to urea fertilizer which are expected to reduce emissions. Costs of these measures would include the differential price of more expensive fertilizers or of inhibitors.

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 fertilizer-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 fertilizer 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 fertilizer is not placed so close to the seed that germination is inhibited. The NH_3 emissions from placement of fertilizers have been estimated to be negligible (assuming that N supply is dimensioned correctly). Deep placement of fertilizer granules is a common technology and has been used for many years in Finland (Aura, 1967).

Application of fertilizer-N when the meteorological conditions are cool and moist or directly prior to probable rainfall will reduce NH_3 emissions. In general, increasing nitrogen use efficiency by proper timing of fertilization and matching crop demands will reduce all N fertilizer use, NH_3, N_2O, NO emissions and nitrate leaching.

Incorporation of fertilizer-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 fertilizer-N applications to grassland may be effective in reducing NH_3 emissions per unit area. However, this will reduce milk yield and live weight 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. Klemedtsson *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 fertilizer-N. As stated in section 3.3.1, such a measure will have a significant cost if it reduces crop yields. However, some scope may remain for better matching of N-fertilizer 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-fertilizing. To reduce the likelihood of excessive N fertilization care should be taken, when deciding N-fertilizer 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 fertilizer-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-fertilizer 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-fertilizer is applied to an actively-growing crop, much of it (especially NO_3^-) may be taken up quickly by the crop, and removed from sites of bacterial activity. Timing of fertilizer-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. For grasslands, adjusting the type of fertilizer to meteorological conditions and avoiding the simultaneous application of organic N fertilizers and nitrate may reduce N_2O emissions by up to 50 % (Clayton *et al.*, 1997).

The effect of fertilizer type on the emission of N_2O is inconclusive (Hénault *et al.*, 1998), and is therefore not included in the IPCC methodology. However, some studies suggest, that fertilizer - induced emissions of N_2O may be greater with the use of anhydrous ammonia and organic N fertilizers (Bouwman, 1996). More recently Dobby and Smith (2002) reported that N_2O emissions from fertilized grasslands can be reduced by applying urea rather than ammonium nitrate based fertilizers.

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.* (1998).

3.3.3 Nitric Oxide

Since, in temperate climates, NO emissions are considered to be predominantly a consequence of nitrification, the use of urea fertilizer may produce larger NO emissions than equivalent amounts of N applied as ammonium nitrate (AN) or any nitrate-based fertilizer. While at present there is insufficient data to discriminate between fertilizer-N sources (Skiba *et al.*, 1997), the substitution of AN for urea to reduce NH_3 and N_2O emissions, may also give some reduction in NO emissions.

Currently the only other possible option is to ensure that applications of N-fertilizer 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-fertilizer applications, and mineralisation of soil N. Fertilizer application should also be timed to match crop demand.

3.3.4 Carbon Dioxide

Soil carbon stocks accumulate by a surplus of input of organic material over decomposition. Any disturbance of the soil system, e.g. by ploughing, drainage, and conversion of forest or grassland to cropland will increase the decomposition rate and hence lead to the release of CO_2. This effect is particularly pronounced in farmed peatlands.

Carbon sequestration in agricultural soils may be encouraged by promoting organic input on arable land instead of grassland (crop residues, cover crops, FYM, compost, sewage sludge), permanent revegetation of arable set-aside land (e.g. afforestation) or extensification of arable production by introduction of perennial components, biofuel production with short-rotation coppice plantations and perennial grasses on arable set-aside land, organic farming, zero tillage *vs* conservation tillage, and the promotion of a permanently shallow water table in farmed peatland (Freibauer *et al.*, 2002).

3.3.5 Methane

Methane is mainly emitted from paddy rice fields (SNAP-code 100103). The emission rate depends on the different water regimes, the length of the growth season, and the duration of flooding (continuous, intermittent, or not flooded). Fertilization and the addition of organic material, as well as the aerenchyma of the specific rice cultivars affect the CH_4 emissions (Heyer 1994; Butterbach-Bahl *et al.*, 1997b; Roger *et al.*, 1999).

Most agricultural soils take up CH_4. The uptake rate depends basically on land use, soil texture and soil aeration, and is reduced by nitrogen availability. In general, CH_4 oxidation rates in agricultural soils is roughly a fifth of native soils. Ammonium inhibition of CH_4 oxidation seems one of the reasons for this decline in oxidation capacity. There is only limited scope for enhancing CH_4 oxidation in agricultural soils by conservation tillage and increased application of organic amendments while it takes decades until the CH_4 oxidation in soil recovers from disturbance (Priemé *et al.*, 1997).

3.3.6 Volatile Organic Compounds

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

4 SIMPLER METHODOLOGY

4.1 Ammonia

4.1.1 Application of Mineral Fertilizer

Noting the interdependence of direct fertilizer emissions and subsequent emissions from foliage and decomposing material of fertilized vegetation, the emissions are treated here as a single integrated term. These are estimated as % losses of the fertilizer-N use for each of the main fertilizer categories. In the simpler 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 fertilizer-plant emission factors are smaller than the totals of ECETOC (1994), since in the original estimates of ECETOC their emissions factors referred to just fertilizer 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 to overestimate NH_3 emissions.

Table 4.1: Simpler methodology estimates of total NH_3 emissions from cultures due to fertilizer volatilization, 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 fertilizers applied.

Fertilizer type	**Present simpler methodology to apply**	**Asman (1992) (Europe)**	**ECETOC (1994) Group II European countries)**	**Sutton *et al.* (1995) (UK)**
Estimates from	fertilizer and plants	fertilizer	fertilizer	Fertilizer and plants
Ammonium sulphate	0.08	0.08	0.10	-
Ammonium nitrate	0.02	0.02	0.02	0.01
Calcium ammonium nitrate	0.02	0.02	0.02	0.01
Anhydrous ammonia	0.04	0.01	0.04	-
Urea	0.15	0.15	0.15	0.10
Nitrogen solution (mixed urea and ammonium nitrate)	0.08	-	0.08	-
Combined ammonium phosphates (generally di-ammonium phosphate)	0.05	0.04	0.05	-
Mono-ammonium phosphate	0.02			
Di-ammonium phosphate	0.05			
Other complex NK, NPK fert	0.02	0.02 - 0.04	0.02	0.025

To calculate NH_3 emissions from fertilized cultures in a country, the use of each fertilizer type (expressed as mass of fertilizer-N used per year), is multiplied by the appropriate emission factor, and the emissions for the different fertilizer types summed. More detailed spreadsheets for this calculation are provided in the detailed methodology (see section 5). Emissions of NH_3-N from fertilizers 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.

4.1.2 Grazed Grassland

To estimate NH_3 emissions from grazed grassland, Pain *et al.* (1997) proposed a function of the form

$$E_{NH3} = c + d\,N \quad \mathbf{(1)}$$

which subsequently was applied to a variety of experimental data sets in Misselbrook *et al.* (2001).

with
E_{NH3} NH_3 emitted (kg a^{-1} NH_3)
c -0.51 kg a^{-1} NH_3
d 0.0742 kg (kg N)$^{-1}$ NH_3
N N excreted (kg a^{-1} N)

to estimate NH_3 emissions from grassland grazed by cattle. Thus, a mean emission factor of 7.5 % of the N excreted is recommended.

No distinction is made between emissions from cattle and sheep excreta. Equation (1) was derived almost entirely from measurements of NH_3 emissions in Northwest Europe. The relationship may not give accurate estimates of emissions from grazing in drier, or warmer climates.

For the amount of N excreted see tables provided in SNAP 100900, Manure Management Regarding Nitrogen Compounds.

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 animal housing and manure storage are dealt with in SNAP Code 100900, Manure Management Regarding Nitrogen Compounds. Emissions arising from biological nitrogen fixation are dealt with in SNAP Code 100200, Cultures without Fertilizers.

The IPCC methodology for the assessment of N_2O emissions from cultures with fertilizers requires the following input data:

1. Total synthetic fertilizer-N applied
2. Total N content of fertilized crop residues 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.

The amount of excreta returned to the soil can be derived from figures calculated in SNAP 100900. The atmospheric emission of NH_3 and/or NO is obtained from this chapter as well as from SNAP 100200 (Cultures without Fertilizers: legumes, grazing animals) and SNAP 100900 (Manure Management Regarding Nitrogen Compounds).

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 Fertilizers (100100, 100200)	- Direct soil emission due to N-inputs including manure (4-5, sheet 1) - 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/deposition from synthetic fertilizer use and grazing animals (4-5, sheet 4, excluding animal waste used as fertilizer) - Indirect emissions due N leaching/runoff from synthetic fertilizer use and grazing animals (4-5, sheet 5, excluding animal waste used as fertilizer)

Total N_2O emission may be calculated as:

$$E_{\mathrm{N2O\text{-}N}} = E_{\mathrm{N2O,\ direct}} + E_{\mathrm{N2O,\ indirect}}$$

Within this SNAP, direct emissions comprise the emissions from (mineral) fertilizer application, application of manures as fertilizers and from farmed organic soils:

$$E_{\mathrm{N2O\text{-}N,\ direct}} = EF_{\mathrm{fert}} \cdot m_{\mathrm{fert}} + EF_{\mathrm{hist}} \cdot A_{\mathrm{hist}} \qquad \textbf{(2)}$$

where		
	$E_{\mathrm{N2O\text{-}N,\ direct}}$	emission flux of N_2O directly emitted from soils ($\mathrm{Mg\ a^{-1}\ N_2O}$)
	EF_{fert}	emission factor for emissions from fertilizers (mineral fertilizer and animal manures) ($EF_{\mathrm{fert}} = 0.0125\ \mathrm{kg\ kg^{-1}\ N}$)
	m_{fert}	amount of N applied with mineral fertilizer and animal manures spread ($\mathrm{Mg\ a^{-1}\ N}$)
	EF_{hist}	emissions factor for emissions from cultivated organic soils ($EF_{\mathrm{hist}} = 8\ \mathrm{kg\ ha^{-1}\ a^{-1}\ N}$
	A_{hist}	area of histosols (ha)

'Net' inputs of animal manure N applied can be obtained from SNAP 100900 as the amount of N excreted (m_{excr}), the N content of straw (m_{straw}) and the amount of NH_3-N, N_2O-N and N_2-N emitted ($E_{\mathrm{NH3\text{-}N}}$, $E_{\mathrm{N2O\text{-}N}}$, $E_{\mathrm{N2\text{-}N}}$):

$$m_{\mathrm{aw}} = (m_{\mathrm{excr}} + m_{\mathrm{straw}}) - (E_{\mathrm{NH3\text{-}N}} + E_{\mathrm{N2O\text{-}N}} + E_{\mathrm{N2\text{-}N}}) \qquad \textbf{(3)}$$

The IPCC guidelines are modified here in order to reach consistency with the NH_3 methodology.

Emissions from crop residues, excreta from grazing animals and from biological N fixation as well as indirect emissions are dealt with in SNAP 100200, Cultures without Fertilizers.

4.3 Nitric Oxide

Current data on NO emissions in relation to fertilizer-N use were reviewed by Yienger and Levy (1995) and were updated by Skiba *et al.*, (1997). Yienger and Levy (1995) calculated an arithmetic mean emission of 2.5 % loss of fertilizer-N. Based on almost the same dataset Skiba et al (1997) showed that NO losses ranged from 0.003 to 11% of applied fertilizer-N with a geometric mean emission of 0.3 %. More recently Bouwman *et* al (2002) used the Residual Maximum Likelihood (REML) technique to calculate from 99 studies of NO emissions a global mean fertilizer induced NO emission of 0.7%. 1 % of applied N was suggested by Freibauer and Kaltschmitt (2000).

It is recommended to use the emission factor 0.7 % of NO-N related to the input of mineral fertilizer N.

4.4 Carbon Dioxide

Carbon dioxide emitted as a consequence of land management and land use change depends strongly on the conditions and direction of change, soil properties, and land management. No simple methodology is suggested.

The IPCC methodology suggests the following emission factors for CO_2 released from farmed organic soils: croplands 3.7 Mg ha^{-1} a^{-1} CO_2 and pastures 1 Mg ha^{-1} a^{-1} CO_2 (IPCC/OECD 1997 Workbook, Chapter 5.6). However, recent measurements in Europe (e.g. Kasimir Klemedtsson *et al.*, 1997) suggest higher emission rates. Therefore, emission factors of 15 ± 5 Mg ha^{-1} a^{-1} CO_2 for arable crops and 10 ± 5 Mg ha^{-1} a^{-1} CO_2 for grasslands are recommended (Freibauer and Kaltschmitt, 2000). These emission factors result from the mineralisation of peat and hence reflect the background emissions in farmed organic soils without fertilization. The emission factors used for and (cereals and row crops), respectively. They suit for farming of organic soils, not for the conversion of peat soils to farmed soils. The uncertainty in the emission factors can be greatly reduced by further long-term measurements.

4.5 Methane

In Europe, most rice paddies are continuously flooded. Methane emissions can be calculated by a simplification of the IPCC Methodology, assuming a uniform water regime. Methane emissions depend on the average air temperature during the growing season, the season length and the area harvested.

$$E_{\mathrm{CH4}} = EF_{\mathrm{CH4}} \cdot (A_{\mathrm{rice}} \cdot t_{\mathrm{rice}}) \qquad \mathbf{(4)}$$

with E_{CH4} emission flux (Gg a^{-1})
EF_{CH4} emission factor (Gg ha^{-1} d^{-1}), representative of the water regime and temperature conditions in a country
A area harvested per year (ha)
t length of season (d)

So far, there is no standard methodology to assess CH_4 consumption in agricultural soils. The CH_4 sink on agricultural soils is estimated at 0.5 ± 0.5 kg ha^{-1} a^{-1} CH_4 (Freibauer and Kaltschmitt 2000). This emission factor relies on a set of 66 long-term measurements in Europe and agrees well with the log-mean oxidation rate of -0.65 kg ha^{-1} a^{-1} CH_4 of agricultural soils in Northern Europe given by (Smith *et al.*, 2000).

4.6 Non-methane Volatile Organic Compounds

The sparse information about emissions of non-methane volatile organic compounds (NMVOCs) does not allow for the construction of a simpler methodology. However, Hobbs *et al.* (2003) have compiled the data presently available. They can be used to provide information of the order of magnitude of NMVOC emissions from agriculture as a first estimate. The use of the following equation and data is recommended for Northern und Central Europe:

$$E_{\mathrm{NMVOC}} = \sum A_{\mathrm{i}} \cdot m_{\mathrm{D,\,i}} \cdot t_{\mathrm{i}} \cdot EF_{\mathrm{i}} \qquad \textbf{(5)}$$

with E_{NMVOC} emission flux (Mg a^{-1} NMVOC)

A_{i} area covered by $crop_{\mathrm{i}}$ (ha)

$m_{\mathrm{D,\,i}}$ mean dry matter of $crop_{\mathrm{i}}$ (Mg ha^{-1})

t_{i} fraction of year during which $crop_{\mathrm{i}}$ is emitting

EF_{i} emission factor (kg kg^{-1} NMVOC)

Table 4.2: Summary of default emission factors for NMVOC emissions from cultures with fertilizer

Crop type	m_D Mg ha^{-1}	T a a^{-1}	EF kg kg^{-1} h^{-1} NMVOC
Temperate grassland	2	0.5	$1.0 \cdot 10^{-8}$
Wheat	2	0.3	$1.1 \cdot 10^{-8}$
Oil seed rape	2	0.3	$2.0 \cdot 10^{-7}$

For further information consult Hobbs *et al.* (2003) and the literature cited therein.

An approach for estimating the emissions from grassland and crop is given in Chapter 110400, Natural Grassland. If the method given in Chapter 110400 is used, emissions from fertilized 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 or regions. 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 fertilizer 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). Based on findings reported or collated by Misselbrook *et al.* (2000) and Harrison and Webb (2001), Sutton *et al.* (2000, 2001, 2002) a detailed approach should consider both mean temperatures for the most impotant period of fertilizer application (March to May) as well as soil pH.

Three climatological regions are to be distinguished according to their mean spring air temperatures t_s:

Region A	$t_s > 13$ °C
Region B	6 °C $< t_s < 13$ °C
Region C	$t_s < 6$ °C

In addition, the effect of calcareous soils whould be considered through use of a multiplier on the basis of values for different areas.

The national or regional inventory should then be calculated as the sum of emissions from each fertilizer type for each region:

$$E_{\mathrm{NH3}} = \sum m_{\mathrm{fert,\,i,\,A}} \cdot EF_{\mathrm{i,\,A}} \cdot c_{\mathrm{i}} + \sum m_{\mathrm{fert,\,i,\,B}} \cdot EF_{\mathrm{i,\,B}} \cdot c_{\mathrm{i}} + \sum m_{\mathrm{fert,\,i,\,C}} \cdot EF_{\mathrm{i,\,C}} \cdot c_{\mathrm{i}} \qquad \textbf{(6)}$$

with E_{NH3} emission flux (Mg a^{-1} NH_3-N)
$m_{fert, i, A}$ mass of fertilizer N applied as type i in region A (Mg a^{-1} N)
$EF_{i, A}$ emission factor for fertilizer type i in region A (kg kg^{-1} N)
c_i multiplier reflecting soil pH

Table 5.1: Detailed methodology emission factors for total NH_3 emissions from soils due to N fertilizer volatilization and foliar emissions for various climatological regions. Values are kg NH_3-N volatilized per kg fertilizer-N applied

Fertilizer type	Region A EF_A	Region B EF_B	Region C EF_C	Multiplier c	Comment
Ammonium sulphate	0.025	0.020	0.015	10	1)
Ammonium nitrate	0.020	0.015	0.010	1	
Calcium ammonium nitrate	0.020	0.015	0.010	1	
Anhydrous ammonia	0.04	0.03	0.02	4	
Urea	0.20	0.17	0.15	1	
Nitrogen solutions	0.11	0.09	0.07	1	2)
Ammonium phosphates	0.025	0.020	0.015	10	1)
Other NK and NPK	0.020	0.015	0.010	1	3)
Nitrate only (e.g. KNO_3)	0.007	0.005	0.005	1	

1) Note very strong pH effect supported by measurements and chemical principles (Harrison and Webb, 2001)
2) saturated solution of urea and ammonium nitrate
3) for fertilizers largely based on ammonium nitrate

With 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; Gosse *et al.*, 1999), NH_3 loss from urea is less dependent on initial soil pH, since hydrolysis of urea will increase pH immediately around the fertilizer granule to *c.* 9.2 (Fenn, 1988). Moreover reaction with calcium ions reduces the volatilization potential of $(NH_4)_2CO_3$ produced by urea hydrolysis (Fenn and Hossner, 1985). In contrast to other N-fertilizers, 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).

Van der Weerden and Jarvis (1997) and subsequently Harrison and Webb (2001) reviewed data from field measurements in Regions B and C of NH_3 loss following application of N fertilizers 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).

It is obvious that the effects on emission factors of grassland *vs* arable land application exceed the climatological differentiation. Therefore, it seems justified to replace the emission factors given in Table 5.1 by separate emission factors for grassland and arable land according to Table 5.2, if the respective activity data are available.

Table 5.2: Detailed methodology emission factors for total NH_3 emissions from arable and grassland soils due to N fertilizer volatilization and foliar emissions for regions B and C.
Values are kg NH_3-N per kg fertilizer-N applied.

Fertilizer type	Grassland $EF_{A, B, gr}$	Arable land $EF_{A, B, ar}$
Ammonium nitrate	0.016	0.006
Calcium ammonium nitrate	0.016	0.006
Urea	0.23	0.115
Nitrogen solutions	0.12	0.06
Other NK and NPK	0.016	0.006

5.1.2 Emissions from Grazed Grassland

The method for calculating NH_3 emissions from grazed grassland is given in Section 4.1. No detailed methodology has been established.

5.1.3 Emissions from Rice Fields

Losses of NH_3 following applications of N-fertilizer 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 kg NH_3-N per kg urea-N applied should therefore be used to calculate NH_3 emissions from flooded rice fields.

As noted above, application of fertilizer-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 4.1.

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 4.1. 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

5.2.1 Nitrous Oxide – Improved Methodology

Climate, weather and soil conditions exhibit a similarly important control on N_2O emissions from agricultural soils as management and fertilization. Against this background, improved methodologies were developed on the basis of multivariate regression analysis (Europe: Freibauer and Kaltschmitt, 2002; UK: Sozanska *et al.*, 2002).

Freibauer and Kaltschmitt (2002) reviewed European data of long-term field measurements and derived and applied statistical equations for annual N_2O fluxes (Freibauer 2002):

- Mineral arable soils in the temperate oceanic and Mediterranean climate (without pronounced frost in winter):

$$E_{\mathrm{N2O}} = \alpha + \beta \cdot m_{\mathrm{fert}} + \gamma \cdot \rho_{\mathrm{C}} + \delta \cdot \rho_{\mathrm{sand}} \qquad \mathbf{(7)}$$

with	E_{N2O}	emission flux of N_2O (Mg ha^{-1} a^{-1} N_2O)
	α_1	constant ($\alpha_1 = 0.6$ kg ha^{-1} a^{-1} N_2O)
	β_1	factor ($\beta_1 = 0.002$ kg kg^{-1})
	m_{fert}	amount of fertilizer N applied (kg ha^{-1} a^{-1} N)
	γ_2	factor ($\gamma_1 = 12.7$ kg g^{-1} ha^{-1} N_2O)
	ρ_{C}	organic carbon content in topsoil (g kg^{-1} of soil weight in A horizon)
	δ_1	factor ($\delta_1 = -\ 0.24$ kg g^{-1} ha^{-1} N_2O)
	ρ_{sand}	sand content in topsoil (kg kg^{-1} of soil weight in A horizon)

- Mineral arable soils in the pre-alpine, alpine and sub-boreal climate regions (with severe frost and regular snow cover):

$$E_{\mathrm{N2O}} = \alpha_2 + \beta_2 \cdot m_{\mathrm{fert}} + \varepsilon_2 \cdot \rho_{\mathrm{N}} \qquad \mathbf{(8)}$$

with	E_{N2O}	emission flux of N_2O (Mg ha^{-1} a^{-1} N_2O)
	α_2	constant ($\alpha_2 = -1.3$ kg ha^{-1} a^{-1} N_2O)
	β_2	factor ($\beta_2 = 0.03$ kg kg^{-1})
	m_{fert}	amount of fertilizer N applied (kg ha^{-1} a^{-1} N)
	ε_2	factor ($\varepsilon_2 = 280$ kg g^{-1} ha^{-1} N_2O)
	ρ_{C}	total nitrogen content in topsoil (g kg^{-1} of soil weight in A horizon)

- Mineral grassland soils in the temperate and sub-boreal climate regions:

$$E_{\mathrm{N2O}} = \alpha_3 + \beta_3 \cdot m_{\mathrm{fert}} \qquad \mathbf{(9)}$$

with	E_{N2O}	emission flux of N_2O (Mg ha^{-1} a^{-1} N_2O)
	α_3	constant ($\alpha_3 = 2.4$ kg ha^{-1} a^{-1} N_2O)
	β_2	factor ($\beta_2 = 0.015$ kg kg^{-1})
	m_{fert}	amount of fertilizer N applied (kg ha^{-1} a^{-1} N)

- Farmed organic soils (grassland and cereal crops):

$$E_{N2O} = 7\ (6\text{-}9)\ \text{kg ha}^{-1}\ \text{a}^{-1}\ N_2O\text{-}N \qquad \mathbf{(10)}$$

- Farmed organic soils (vegetables and root crops):

$$E_{N2O} = 20\ (10\text{-}30)\ \text{kg ha}^{-1}\ \text{a}^{-1}\ N_2O\text{-}N \qquad \mathbf{(11)}$$

It should be noted that the emission factors for organic soils do not fit the factor given by the IPCC Guidelines.

5.2.2 Nitrous Oxide – Detailed Methodology

N-trace gas emissions from soils are the result of different microbial and physico-chemical processes, i.e. mainly of nitrification and denitrification for NO and N_2O and chemo-denitrification at soil pH-values < 5.0 for NO, occurring simultaneously in the soil. The magnitude of processes involved in N-trace gas production is strongly controlled by other biotic processes (e.g. mineralization, plant N-uptake) or by abiotic factors like e.g. temperature, soil moisture or fertilization and N-deposition, which do change substantially on spatial and temporal scales. Therefore, significant improvements of current estimates of N-trace gas fluxes from soils may only be achieved, if mechanistic models are developed and used, which are able to predict N-trace gas emissions based on the processes involved in N-trace gas production/ consumption and emission (Butterbach-Bahl *et al.*, 2001). Such mechanistic models have currently been developed, e.g. DNDC (e.g. Li *et al.*, 1992, 2000) and CENTURY (e.g. Parton *et al.*, 1996) and have already been applied at a regional scale for calculations of N-trace gas emission inventories (Brown *et al.*, 2002; Butterbach-Bahl *et al.*, 2002).

For a detailed regression orientated approach see Sozanka *et al.* (2002).

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).

$$E_{NO} = \alpha \cdot e^{\zeta \cdot t_s} \qquad \mathbf{(12)}$$

where E_{NO}	emission flux (ng m^{-2} s^{-1} NO-N)
α	experimentally derived constant for the land use types of grasslands and pasture, forests and urban trees, and the individual agricultural categories (SNAP code 11, Table 8.1)
ζ	factor ($\zeta = 0.071\ K^{-1}$)
t_s	soil temperature (°C)

To improve this approach, N input and soil moisture contents (Meixner, 1994) need to be included in the equation. Furthermore, also the soil pH is crucial determinant, since NO can be produced at soil-pH < 4.0 also by chemo-denitrification. A multiple regression approach was developed by Sozanska (1999, see Skiba *et al*, 2001). Soil NO emissions were calculated from the N input and the water filled pore space of the soil

$$\ln E_{\mathrm{NO}} = -0.82 + 0.354 \ln N_{\mathrm{input}} + 0.0036\,(-WFPS^2 + 80\,WFPS - 1593) \qquad \mathbf{(13)}$$

where E_{NO} emission flux (kg N ha^{-1} y^{-1})
N_{input} input of N to soil by fertilizer, animal excreta, N deposition (kg ha^{-1} a^{-1} N)
$WFPS$ water filled pore space (%)

The Williams approach produces much greater estimates of NO emission than are given by the simpler methodology, whereas Sozanska's multiple regression model produces much smaller estimates than the simple methodology. The authors conclude that due to the lack of data it is not appropriate to use either methodology at this stage.

As mentioned already for N_2O, an improvement of estimates of NO emissions from soils may only be achieved by use of detailed mechanistic models, which allow to calculate simultaneously production, consumption and emission of NO from soils with regard to all processes involved.

5.4 Carbon Dioxide

No detailed methodology is suggested.

5.5 Methane

No detailed methodology is suggested.

At least with regard to CH_4-emissions from rice paddy fields progress has been achieved by using mechanistic models in order to calculate CH_4-emission form a plot up to a regional scale (van Bodegom *et al.*, 2001; Segers and Kengen, 1998; Denier van der Gon *et al.*, 2000).

5.6 Non-methane Volatile Organic Compounds

A detailed methodology is not available.

6 RELEVANT ACTIVITY STATISTICS

Information is required on the annual consumption of major N-fertilizer types by each country. In principle, this may be obtained from IFA (2002) 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 100900, Manure Management Regarding Nitrogen Compounds. 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 fertilized culture emissions are required (section 12), information on the spatial distribution of different crop types and average N-fertilizer inputs to each crop type may be used. In the absence of data on the use of different fertilizers for crop types, the average N-fertilizer inputs to crops may be combined with the average NH_3 emission factor for a country estimated according to Tables 6.1, 6.2 and 6.3 as: Total $NH_3/N_2O/NO$ emission/total N-fertilizer consumption. All the activity statistics required are summarized in Table 6.4.

For the improved methodology for N_2O emission, additional information on soil texture, top-soil organic carbon and total nitrogen content is required.

Table 6.1: Spreadsheet for calculating NH_3 emissions from grassland and arable land with fertilizers according to either the simpler or the detailed methodologies

Group of country (for detailed methodology)			
Column	A	B	C
Fertilizer type	N emission factors (from Table 4.1 or 5.1) kg NH_3-N per kg N applied a^{-1}	Fertilizer use kg N a^{-1} (see section 6)	Ammonia emissions kg NH_3 a^{-1} ($A \cdot B \cdot 17/14$)
Ammonium sulphate			
Ammonium nitrate			
Calcium ammonium nitrate			
Anhydrous ammonia			
Urea			
Mono-ammonium phosphate			
Di-ammonium phosphate			
Other complex NK, NPK fertilizers			
Nitrogen solution (mixed urea and ammonium nitrate)			
Total ammonia emissions in kg NH_3 per year			

Table 6.2: Spreadsheet for calculating nitrous oxide emissions from cultures with fertilizers according to either the simpler methodology or the more complex methodology

	A	B	
N input	N emission factor kg N_2O-N per kg ‘net’ N applied	N input in kg a^{-1} N	N_2O emission in kg N_2O a^{-1} ($A \cdot B \cdot 44/28$)
Fertilizer- N	0.0125		
Crop residues N	0.0125		
Excretal- N deposited during grazing	0.020		
	kg ha^{-1}	Area (ha)	
Cultivation of histosols	5		

Table 6.3: Spreadsheet for calculating nitric oxide emissions from cultures with fertilizers according to the simple methodology

	A	B	
N input	NO emission factor kg NO-N per kg N applied	Fertilizer-N use in kg N a^{-1}	Nitric oxide emission kg NO a^{-1}
			(A · B · 30/14)
Fertilizer-N	0.007		

Table 6.4: Summary of activity statistics which may be required for the simple and detailed methodologies.

Activity Statistic		Source
Synthetic Fertilizer-N use	By type of fertilizer for arable and grassland	IFA or national statistics
Amount and N concentration of fertilized 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 100900, Manure Management Regarding Nitrogen Compounds
Area of cultivated histosols		FAO, See IPCC/OECD (1997)
Topsoil sand, organic carbon and total nitrogen contents	For arable soils	Combined soil / land use map

Spreadsheets for calculations of emissions according to improved or detailed methodologies can be found at The UNECE Task Force on Emission Inventories and Projections homepage (http://www.aeat.co.uk/netcen/airqual/TFEI/unece.htm, Supplementary Technical Information)

7 POINT SOURCE CRITERIA

Ammonia, N_2O, NO, CH_4 and VOC emissions from cultures with fertilizers 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 fertilizers, are treated as kg of N per kg N applied as fertilizer or, in the case of crop residues incorporated into the soil, and excretal-N deposited during grazing, of the N returned in these forms. Emissions of CH_4 and of CO_2 and N_2O from farmed organic soils are given per hectare and year. Full details of calculations are provided in sections 5 and 6.

9 SPECIES PROFILES

9.1 Volatile Organic Compounds

As with forest NMVOC emissions, biogenic emissions from grasslands consist of a wide variety of species, including isoprene, monoterpenes, (α-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.*, 1995). although many more measurement data will be required before reliable attempts to inventory specific OVOC can be made.

10 UNCERTAINTY ESTIMATES

10.1 Ammonia

Although the processes governing the emission of NH_3 from fertilizers and crops are reasonably well understood, the interactions of many biological, chemical and environmental factors make quantitative estimates of emission rather uncertain. Key uncertainties that require further attention include:

- The extent of the temperature effect is in principle quite clearly based on physico-chemical principles. However, it is noted that warm conditions tend to be more drying due to a larger vapour pressure deficit.
- There in no effect of soil pH on emissions from ammonium nitrate and calcium ammonium nitrate in practice for emissions from grassland, as the results of GRAMINAE suggest. However, there may be some effect of pH for bare soils.
- The emission rate from anhydrous ammonia is considered to be particularly uncertain. Anhydrous ammonia is normally applied under pressure by deep injection into arable soils. Basic thermodynamics would suggest that there is a clear effect effect of both temperature and soil pH.
- Experimental data show that the vegetation mediated NH_3 emissions from fertilized cultures may be extremely variable depending on climate conditions. In principle, larger emissions are expected in warm conditions. However, Schjørring *et al.* (1991) found that under cool wet summer conditions with poor growth, grainfilling of cereals was less effective than in warm summer conditions, and this coupled with higher ammonia emissions.
- Comparative measurements of NH_3 emissions from urea as contrasted to ammonium nitrate almost always show much larger rates of NH_3 emission. However, the actual rate is extremely variable, with lowest emissions in very wet and cold conditions (e.g. 2 % volatilization, measured by Nemitz *et al.*, 2001). Some moisture is necessary for urea hydrolysis, so the largest emissions are likely to occur in warm drying conditions where application is made onto a soil following rain (Harrison and Webb, 2001). The values are based on an average of measurements for grassland and arable soils, where emissions from the latter are half those on grassland due to frequent incorporation of urea into arable soils (Misselbrook *et al.*, 2000).

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 %. Overall emissions are probably no better than ± 50 %.

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 started to be accurately modelled in mechanistic models such as DNDC, PnET-N-DNDC and CENTURY. Application of fertilizer-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 fertilizer-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 the IPCC methodology. 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. Recent reviews suggest that the indirect N_2O emissions from leaching and runoff tend to be overestimated (Nevison 2000; Groffman *et al.*, 2000).

For typical soil conditions and fertilization rates under common agricultural practice in Europe and mean flux rates, the regression models of the improved methodology for N_2O have a mean standard error of 40 to 50 % (equation 7), 30 % (8) and 70 to 100 % (9).

10.3 Nitric Oxide

Although much less information is available on factors determining losses of NO from soils (N input, soil temperature and soil moisture), data, especially long-term intensive field experiments are not available to provide a good degree of certainty in the estimate. While application of fertilizer-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.

10.3 Carbon Dioxide

10.4 Methane

The uncertainty in the soil CH_4 sink is 100 %. The uncertainty with regard to CH_4 emissions from rice paddy fields is still significant, since the magnitude of emissions is strongly affected by environmental parameters like e.g. temperature, soil properties and by field management (fertilization, drainage, cultivar). Thus, the estimates may show an error of 50 - 100 %.

10.5 Non-methane Volatile Organic Compounds

Biogenic VOC emissions for the UK were summarized by Hewitt and Street (1992). These ranged from 38-211 Gg a^{-1} total NMVOCs. Emissions from woodlands were estimated to be 72 % of total biogenic emissions by Anastasi *et al.* (1991). Thus between *c.* 10 and 59 Gg a^{-1} appear to be of agricultural origin. In their incomplete analysis Hobbs *et al.* (2003) calculated c. 5 Mg a^{-1} from agricultural plants. This compares with the CORINAIR 94 estimate of only 2 Gg a^{-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 North 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 North and West Europe.

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

11.1 Ammonia

A major criticism of the present simpler 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. Soil pH and temperature need to be included in the methodology with first priority. This could be realised by deriving functions as a synthesis of existing literature or from mechanistic modelling. More work needs to be done in the development of mechanistic process-based models for predicting NH_3 emissions from N-fertilizers and the foliage of fertilized crops, which take into account the known physico-chemical equilibria as well as interactions with biological processes to predict net fluxes. Such models are under development (Rachpal-Singh and Nye, 1993; van der Molen *et al.*, 1990; Génermont and Cellier, 1997). They could be used to derive different functions in order to account for the effects of different environmental factors (temperature, rain, pH, …). 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 (Sutton *et al.*, 2000). Studies of NH_3 emissions from grazed grassland have largely been carried out in Northwest Europe. Data is needed on emissions in warmer and drier climates. For grazed grasslands, more measured data are generally needed.

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. Process-based models should run on daily time steps in order to capture the variability of N_2O emission rates and of their controlling factors. Such models could be used to refine and adjust emission factors and to monitor N_2O reduction meassures (Brown *et al.*, 2002, Butterbach-Bahl *et al.*, 2002). Emissions of N_2O per kg fertilizer-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 fertilizer-N sources needs to be addressed.

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. Also integrated studies on watershed level are needed in order to quantify the relation between N input on the agricultural area and N_2O emissions in surface waters downstream.

11.3 Nitric oxide

Reliance on a simple fixed (%) emission factor in relation to the amount of N-fertilizer 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-fertilizer 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. Again, NO emissions should be linked with N input, soil and climatic conditions by using process-based models. The mechanistic models DNDC and CENTURY have been extended to cover NO emissions.

11.4 Carbon Dioxide

11.5 Methane

The CH_4 sink in agricultural soils is small, so the large uncertainty does not introduce a large error in the national inventories. Therefore, no major need for improvement is seen at present stage.

11.6 Non-methane Volatile Organic Compounds

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

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

12.1 Ammonia

The simplest approach to spatially disaggregate the emissions from cultures with fertilizers is to scale these by the distribution of total arable and fertilized grassland. In a more detailed approach census data on the distribution of different crop types may be combined with characteristic fertilizer inputs to each crop type, together with the overall fertilizer emissions factor estimated from Table 4.2. Where the average N-fertilizer application to crops is derived from similar national data as the fertilizer 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 fertilizer/foliar emissions from grazed grassland, noted in the detailed methodology (section 5).
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 fertilizer-N inputs to those crops. Data on the distribution of organic soils (histosols) and on soil moisture regimes in mineral soils 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, but some biogeochemical models such as DNDC (Li *et al.*, 1992) and CENTURY (Parton *et al.*, 2001) can be readily adjusted to European conditions, are being adjusted, or have already been (Brown *et al.*, 2002; Butterbach-Bahl *et al.*, 2002). Dividing the country/region into 3 to 4 climatic and soil groups and slightly modifying the IPCC methodology, by increasing and reducing the various emission factors for the individual regions, or by using simple linear regression models may be a step forward.

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

Due to the long atmospheric lifetime of N_2O, spatial resolution is not really needed.

12.3 Nitric Oxide

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

12.4 Carbon Dioxide

12.5 Methane

The location of rice paddies is available from land use surveys. Within agricultural soils, the sink strength for CH_4 is small enough that no significant error is introduced to emission/removal maps if agricultural land is treated in a uniform way, even though the relative spatial variability in the CH_4 sink is large.

12.6 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 fertilizers and crops. Most of the direct emission from N-fertilizer occurs within a month of application and, for some countries, agricultural statistics and knowledge from common agricultural practice 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 ha^{-1} NH_3 emission (Schjørring and Mattsson, 2001). A major uncertainty with fertilizer, 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 fertilizer-N occurs within a few weeks of application (Bouwman, 1996), and during freeze-thaw events in spring. Statistics on the timing of fertilizer-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 N_2O production by denitrification and nitrification.

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 and in acid soils as a consequence of chemo-denitrification. Peaks in NO emission are therefore likely following application of NH_4^+-based N-fertilizers, 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 (Butterbach-Bahl *et al.*, 2002). In common with NH_3 and N_2O, emissions may vary greatly from year to year, depending upon weather conditions.

13.4 Carbon Dioxide

13.5 Methane

Both methanogenesis and CH_4 oxidation show clear seasonal trends in dependence of soil temperature and soil aeration status.

13.6 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 fertilized 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. Efforts to establish integrated models to quantify emissions from agricultural land should be undertaken, coupling soil, climatic and process information with GIS methods.

15 SUPPLEMENTARY DOCUMENTS

The main supplementary documentation required for applying the estimates in this chapter are details of national N-fertilizer consumption and areas of fertilized 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.

The use of temperature and soil pH dependent data presupposes knowledge and documentation of regional spring air temperatures and soil pH distribution.

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.

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20 Point of Enquiry

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SNAP CODES :	**100201** **100202** **100203** **100204** **100205** **100206**
SOURCE ACTIVITY TITLE :	**CULTURES WITHOUT FERTILIZERS** **(Unfertilized Agricultural Land)** ***Permanent Crops*** ***Arable Land Crops*** ***Rice Field*** ***Market Gardening*** ***Grassland*** ***Fallows***
NOSE CODES :	**110.02.01** **110.02.02** **110.02.03** **110.02.04** **110.02.05**
NFR CODES :	**4D1** **4C**

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). By definition, cultures without fertilizers are soils cultivated for crop production and grasslands, for cutting and grazing, which are not given N-fertilizer (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 fertilizer-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 100900, Manure Management Regarding Nitrogen Compounds.

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

This chapter is comprised of the following sub-codes.

100201	Permanent Crops
100202	Arable Land Crops
100203	Rice Field
100204	Market Gardening
100205	Grassland
100206	Fallows

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

2 CONTRIBUTIONS TO TOTAL EMISSIONS

The major source of NH_3 emissions in Europe is volatization from livestock excreta. Ammonia may also be emitted from the application of N-fertilizers and from fertilized crops. Emissions from unfertilized crops are usually considered to be negligible, although 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 fertilizers and animal manures to land. 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 following the deposition of other N compounds (NH_3 and NO_x) to unfertilized 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 fertilizers are extremely uncertain.

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

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 from cultures without are all < 1 % of current total emission estimates, though agriculture as a whole or global emissions from soils as a whole may play a dominant role even for species which at present receive little attention (NO: Davidson and Kingerlee, 1997). These do not therefore require a methodology for calculation. However given current uncertainties over the magnitude of emissions from unfertilized 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 fertilizer-N (Sutton et al., 1995). There is very little information on ammonia emissions from cultures without fertilizers. Significant emissions are not expected from unfertilized crops (with the exception of legumes).

Crops of agricultural legumes, while not given fertilizer-N, have been estimated to fix amounts of N as great, or greater than applied as fertilizer to agricultural crops (Sylvester-Bradley, 1993, Vitousek *et al.*, 2002). Thus emissions of NH_3 may be expected to be similar to those from fertilized agricultural crops (e.g. 0 - 15 kg $ha^{-1}a^{-1}$, 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} a^{-1} NH_3-N from an alfalfa crop. Harper *et al.* (1989) found net depositions of 0.4 - 3.1 kg ha^{-1} a^{-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 ha^{-1} N) emissions early in the season were balanced by deposition (2 - 3 kg ha^{-1} N) 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 fertilized 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 unfertilized 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 fertilizer-N had been applied.

Ammonia emissions from unfertilized grass, grazed by livestock, have been made by Jarvis *et al.* (1989, 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 ha^{-1} a^{-1} N), and *c.* 70 % of NH_3 emissions from grazed grassland given 210 kg ha^{-1} a^{-1} N. Jarvis *et al.* (1991) measured NH_3 emissions from pastures grazed by sheep, including an unfertilized clover monoculture. Emissions of NH_3 from the unfertilized grass/clover pasture (2 kg ha^{-1} a^{-1} N) were less than from an unfertilized grass field (4 kg ha^{-1} a^{-1}), whilst emissions from the pure clover pasture (11 kg ha^{-1} a^{-1} N) were greater than from grassland given 420 kg ha^{-1} a^{-1} N. 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^{-1} from unfertilized 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 unfertilized 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 fertilizers as the sum of direct soil emissions and indirect emissions. Direct soil emissions from cultures without fertilizer 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 unfertilized soils.

In soil N_2O is produced predominantly by nitrification, *i.e.* the oxidation of ammonium (NH_4^+) to nitrate (NO_3^-), and denitrification, *i.e.* the reduction of NO_3^- to gaseous forms of N: N_2O and N_2. In most soils, these processes are active simultaneously with varying proportions (e.g. Stevens *et al.*, 1997). The rate of N_2O production is to a large extent dependent on the availability of mineral N in the soil (Bouwman 1996), but also on soil pH and management practices (Kaiser *et al.*, 1996, Yamulki *et al.*, 1997, Pathak, 2001, Yamulki and Jarvis, 2002). With respect to the amount of nitrogen added to soils, grassland systems emit more N_2O than arable land systems. Soils are likely to act as a weak sink for N_2O if the nitrogen supply is very low (Conrad and Dentener, 1999, Butterbach-Bahl *et al.*, 2002 a). 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, Teepe *et al.*, 2001, Butterbach-Bahl *et al.*, 2002 b).

Little information is available on the emission of N_2O from legumes: Wagner-Riddle *et al.* (1997) reported emissions of *c.* 6 kg ha^{-1} a^{-1} N_2O from soybeans and alfalfa, Flessa *et al.* (2002) 9 kg ha^{-1} a^{-1} N_2O from legumes as catch crops.

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.

The emission of nitrous oxide, which is related to the transformation of nitrogen species which originate from agricultural emissions of NH_3 and NO, but are deposited elsewhere, or are emitted from contaminated ground water after pressure reduction, are called indirect emission. Such soil and environmental factors as mentioned above are also likely to influence the magnitude of indirect N_2O emissions following atmospheric deposition of NH_3 and NO_x or their reaction products.

3.1.3 Nitric Oxide

Nitric oxide (NO) may be emitted from unfertilized soils as a consequence of nitrification or denitrification. If soils are maintained at pH > 5.0, NO emission is likely to be mainly from nitrification (Remde and Conrad 1991; Skiba *et al.*, 1997). Increased nitrification is likely to occur following soil cultivation and incorporation of crop residues (Aneja *et al.*, 1997). Activities such as tillage and incorporation were considered to increase NO emissions by a factor of 4 (Skiba *et al.*, 1997, 2002; Civerolo and Dickerson, 1998), for periods of between 1 and 3 weeks.

A major determinant of NO production in agricultural soils is mineral N concentration, which in unfertilized cultures is increased by residue incorporation and cultivation. Soil moisture content, soil temperature and N partitioning into the crop seem to be similarly important (Aneja *et al.*, 1996, Skiba *et al.*, 1997). As a first approximation, 0.7 % of N inputs may be expected to be lost as NO, as per SNAP Code 100100, Cultures with Fertilizers. 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 unfertilized 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:

- Activities that emit VOCs by combustion or evaporation;
- Land clearing, including burning;
- Biogenic processes.

The primary sources in the agricultural sector are:

- Burning stubble and other plant wastes;
- The use of organic solvents in pesticide production;
- Anaerobic degradation of livestock feed and animal excreta;
- Emissions from plants.

At present, all these 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 Regarding Carbon Compounds.

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 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 (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 North 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 North and West Europe.

For direct emissions from agricultural plants see 100100, Cultures with Fertilizers.

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.

Unfertilized agricultural grassland. Grassland, to be used for either cutting grass for conservation, grazing or both, to which synthetic N-fertilizers have **not** been applied. Phosphorus or potassium fertilizers 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 fertilizers. 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 fertilizer-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 unfertilized 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

4.4.1 Legumes

Since legumes are the only arable crops regarded as sources of NH_3 in cultures without fertilizers, 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} a^{-1} NH_3-N.

4.4.2 Animal grazing

If the amount of nitrogen excreted cannot be obtained from SNAP 100900, Manure Management Regarding Nitrogen Compounds, the following emission factors (kg ha^{-1} a^{-1} NH_3-N) are proposed for all unfertilized pastures grazed by cattle, and for lowland pastures grazed by sheep :

Grass/clover:	cattle 7, sheep 2;
Unfertilized grass:	cattle 4, sheep 4.

These emission factors are taken from studies of grazing emissions by Jarvis *et al.* (1989, 1991). Greater emission factors from unfertilized 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 fertilizer-N of up to c. 200 kg ha^{-1} N in Chapter 100100, Cultures with fertilizers. These anomalies emphasise the lack of data available on NH_3 emissions from unfertilized, grazed grass, and hence the uncertainty of this component of the Emission Inventory.

If nitrogen excretion by grazing animals can be assessed by SNAP 100900, the methodology given in SNAP 100100 should be applied to achieve emissions from grazing:

To estimate NH_3 emissions from grazed grassland, Pain *et al.* (1997) proposed a function of the form

$$E_{NH3} = c + d\,N \quad \textbf{(1)}$$

which subsequently was applied to a variety of experimental data sets in Misselbrook *et al.* (2001)

with E_{NH3} NH_3 emitted (kg a^{-1} NH_3)
c -0.51 kg a^{-1} NH_3
d 0.0742 kg (kg N)$^{-1}$ NH_3
N N excreted (kg a^{-1} N)

to estimate NH_3 emissions from grassland grazed by cattle. Thus, a mean emission factor of 7.5 % of the N excreted is recommended.

For further details see SNAP 100100, paragraph 4.1.2.

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).

Care is to be taken that double counting of emissions from grazed grassland in SNAPs 100100 and 100200 is avoided.

4.2 Nitrous Oxide

Following the IPCC methodology (IPCC/OECD, 1997), N_2O emissions from unfertilized 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).

The respective input data can be estimated from FAO data (see IPCC/OECD 1997) (Table 4.1) (http://apps.fao.org/default.htm)

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.

Total N_2O emission are subdivided in direct and indirect emissons:

$$E_{\text{N2O-N}} = E_{\text{N2O, direct}} + E_{\text{N2O, indirect}}$$

4.2.1 Direct emissions

Within SNAP 100200, direct emissions comprise the emissions from grazing animals and from crop residues:

$$E_{\text{N2O-N, direct}} = EF_{\text{crop}} \cdot m_{\text{crop}} + EF_{\text{graz}} \cdot m_{\text{graz}} \qquad \textbf{(2)}$$

where	$E_{\text{N2O-N, direct}}$	emission flux of N_2O directly emitted from soils (Mg a^{-1} N_2O)
	EF_{crop}	emission factor for emissions from crop residues ($EF_{\text{crop}} = 0.0125$ kg kg^{-1} N)
	m_{crop}	amount of N in crop residues (Mg a^{-1} N)
	EF_{graz}	emission factor for emissions from grazing ($EF_{\text{graz}} = 0.02$ kg kg^{-1} N)
	m_{graz}	amount of N in excreta dropped during grazing (Mg a^{-1} N)

The IPCC default value is likely to underestimate N_2O emissions (e.g. Flessa *et al.*, 2002)

The amount of N left with residues will have to be calculated for each crop as the product of area covered by the crop, the total dry matter left unharvested for later incorporation, and the N content according to

$$m_{\text{crop}} = \sum A_{\text{i}} \cdot m_{\text{i}} \cdot N_{\text{i}} \qquad \textbf{(3)}$$

where	A_{i}	area covered by crop i (ha)
	m_{i}	dry matter of crop i (Gg a^{-1})
	N_{i}	concentration of N in dry matter of crop i (kg kg^{-1} N)

Emissions from grazing should be calculated under SNAP 100900, Manure Management Regarding Nitrogen Compounds. If SNAP 100900 cannot be used, default excretion factors are to be used. Prior to estimation of direct N_2O emissions, excretal N returns are reduced by 20 % to allow for N lost as NH_3. However those values are likely to be an overestimate for unfertilized grass as they are averages across a range of production systems and both fertilized and unfertilized grassland.

The amount of N dropped during grazing of an animal category j is a function of the amount of N excreted and the duration of the grazing period; it also depends on animal behaviour:

$$m_{\text{graz}} = \sum \left(n_{\text{j}} \cdot m_{\text{excr, j}} \cdot t_{\text{graz, j}} \cdot f_{\text{beh, j}} \right) \qquad \textbf{(4)}$$

where	m_{graz}	amount of N dropped during grazing (kg animal^{-1} a^{-1} N)
	n_{j}	number of animals in category j (animals)
	m_{excr}	mean rate of N excreted (kg animal^{-1} a^{-1} N)
	t_{graz}	share of grazing period (d d^{-1})
	f_{beh}	factor reflecting animal behaviour which leads to an uneven distribution of droppings between animal house and pasture/paddock (dimensionless)

4.2.2 Indirect emissions

Indirect emissions comprise emissions resulting from atmospheric deposition of reactive nitrogen species and from leached and/or run-off nitrogen:

$$E_{\mathrm{N2O\text{-}N,\ indirect}} = EF_{\mathrm{dep}} \cdot m_{\mathrm{dep}} + EF_{\mathrm{leach}} \cdot m_{\mathrm{leach}} \qquad \textbf{(5)}$$

where	$E_{\mathrm{N2O\text{-}N,\ indirect}}$	emission flux of N_2O indirectly emitted from soils (Mg a^{-1} N_2O)
	EF_{dep}	emission factor for emissions reulting from atmospheric deposition ($EF_{\mathrm{dep}} = 0.01$ kg kg^{-1} N)
	m_{dep}	amount of N deposited (Mg a^{-1} N)
	EF_{leach}	emission factor for emissions from leaching or run-off ($EF_{\mathrm{leach}} = 0.025$ kg kg^{-1} N)
	m_{leach}	amount of N in leachate or run off (Mg a^{-1} N)

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 N_2O losses as a result of NH_3 and NO deposition using the methods described in this section (chapters 100100, this chapter, and 100900), rather than the IPCC default values for reactive nitrogen species emitted from arable or animal agriculture.

It is assumed that the amount of nitrogen deposited equals the amount of reactive nitrogen released. Irrespective of the location of emissions, depositions are calculated as the sum of the NH_3-N and NO-N (E_{NH3}, E_{NO}) released in agriculture.

$$m_{\mathrm{dep}} = \sum (E_{\mathrm{NH3\text{-}N,i}} + E_{\mathrm{NO-N,\,i}}) \qquad \textbf{(6)}$$

For indirect emissions from deposition, observed emission factors sometimes fit the default value (Oura *et al.*, 2001), in many cases this factor leads to an underestimation of N_2O emissions (e.g. Butterbach-Bahl *et al.*, 2002 a, b) and may range from 0.2 to 15 % of the atmospheric N deposited (Skiba *et al.*, 1999).

The amount of nitrogen lost from agricultural fields due to leaching or run-off is estimated to be c. 30 % of the total nitrogen input into soils, *i.e.*:

$$m_{leach} = f_{leach} \cdot \left(m_{fert} + m_{man} + m_{graz} \right) \qquad \textbf{(6)}$$

where	m_{leach}	amount of nitrogen leached (Mg a^{-1} N)
	f_{leach}	fraction of N in leachate or run off (kg kg^{-1} N)
	m_{fert}	N input into soil with mineral fertilizers (Mg a^{-1} N)
	m_{man}	N input into soil with manure applied (Mg a^{-1} N)
	m_{graz}	N input into soil during grazing (Mg a^{-1} N)

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 Fertilizers (100100, 100200)	- Direct soil emission due to N-inputs including manure (4-5, sheet 1) - 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/deposition from synthetic fertilizer use and grazing animals (4-5, sheet 4, excluding animal waste used as fertilizer) - Indirect emissions due N leaching/runoff from synthetic fertilizer use and grazing animals (4-5, sheet 5, excluding animal waste used as fertilizer)

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

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

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

† Manure N inputs, other than from animals during grazing. are dealt with in SNAP Code 100900, Manure Management Regarding Nitrogen Compounds.

4.3 Nitric Oxide

An estimate of the amount of crop residues, together with their N concentrations, returned to unfertilized soils, together with an estimate of excretal N deposited during grazing would provide estimate of NO emissions.

Indirect emissions of NO are in the same order of magnitude as N_2O emissions (*e.g.* Butterbach-Bahl *et al.*, 2002 a, Jensen *et al.*, 2002, Yamulki and Jarvis, 2002) or may exceed them (Butterbach-Bahl *et al.*, 1997). Therefore, it seems justified to treat them in the same way as other NO emissions from soils and assuming 0.7 % 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:

$$E_{\mathrm{NH3}} = \sum \left(A_{\mathrm{leg,i}} \cdot NF_{\mathrm{i}} \cdot EF_{\mathrm{NH3}} \right) \qquad \textbf{(7)}$$

where		
	E_{NH3}	NH3 emitted (kg a^{-1})
	$A_{\mathrm{leg,\,i}}$	area covered by legume i (ha)
	NF_{i}	nitrogen fixation (kg ha^{-1} N)
	EF_{NH3}	emission factor (0.01 kg kg^{-1} N)

Where information on average N fixation rates for different legume species is unavailable for a country, 100 kg N ha^{-1} a^{-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 unfertilized crop residues left on the surface. The effects of different climates on NH_3 emissions both from unfertilized crops, and from their residues, needs to be known. However emissions from unfertilized cultures are likely to be small in relation to emissions from livestock husbandry.

5.2 Nitrous Oxide

More detailed methodologies for calculating N_2O emissions need to include soil moisture and soil temperature in addition to N input. Multiple linear regression models and process based models (DNDC) have been developed and are outlined in ag 100100, section 5.2 (Butterbach-Bahl *et al.*, 2001, Skiba *et al.*, 2001). Improving the estimate of N deposition will also lead to significant improvements in the N_2O flux estimate. In particular, countries are encouraged to estimate NH_3 losses using the methods described in this Guidebook, 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 and soil temperature. Simple models including the control by temperature (Williams *et al.*, 1992) or soil moisture (Skiba *et al.*, 2001) in addition to N input are outlined in chapter 100100, Section 5.3, of this Guidebook.

However, as there is so little information on soil NO emissions from cultures without fertilizers, it is not appropriate to provide a detailed methodology. Improving the estimate of N deposition rates, and using the detailed methods to calculate N inputs from animal manures (chapter 100900 of this Guidebook) is likely to improve the quality of the emission calculations.

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 unfertilized 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 unfertilized culture emissions are required (section 12), information on the spatial distribution of different legume and other unfertilized crops are required. The distribution of cultivated, but unfertilized 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 100900, Manure Management Regarding N Compounds
Area of cultivated histosols		FAO, see IPCC/OECD (1997)
Atmospheric emissions of NH_3 and NO_x		ETCAE (1997), SNAP Codes 100100 and 100900
N lost from soils by leaching and runoff		FAO, See IPCC/OECD, (1997)

7 POINT SOURCE CRITERIA

NH_3, N_2O, NO and VOC emissions from cultures without fertilizers should be treated as area sources.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

The emission factors for NH_3 losses from cultures without fertilizers are treated as kg ha^{-1} N of leguminous crops and grazed, unfertilized grassland. However, emissions from animal grazing are calculated as kg NH_3. For N_2O, losses are kg N_2O-N per kg N 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 $ha^{-1}N$.

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

	A	**B**	
	Emission factor kg kg^{-1} N_2O-N	N input kg a^{-1} N	N_2O emission, kg a^{-1} N_2O (A * B * 44/28)
Crop residues			
N with crop residues	0.0125		
Excretal-N deposited during grazing	0.020		
Indirect emissions			
Emission of NH_3 Emission of NO_x N lost by leaching or runoff	0.010 0.010 0.025		
	Emission factor 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 (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 unfertilized grassland and leguminous crops, rather than the areas of unfertilized 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 Gg a^{-1} total VOCs. Between *c.* 10 and 59 Gg a^{-1} appear to be of agricultural origin. This compares with the CORINAIR94 estimate of only 2 Gg a^{-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 to differentiate 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 North West Europe. Emissions may be greater in drier and warmer areas, *e.g.* Southern 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 unfertilized 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 unfertilized 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 unfertilized crops and grassland, together with estimates of the N returned in their residues. Data on the distribution of cultivated, unfertilized 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 unfertilized 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 unfertilized 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 unfertilized 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 unfertilized grass distributions.

16 VERIFICATION PROCEDURES

There are no direct methods to evaluate total inventory estimates of NH_3 emissions from unfertilized 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.

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

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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.

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SNAP CODE:	**100401**	**100406**
	100402	**100407**
	100403	**100408**
	100404	**100409**
	100405	**100410**
		100412
SOURCE SUB-SECTOR TITLE:		**ENTERIC FERMENTATION**
	Dairy Cows	***Mules and Asses***
	Other Cattle	***Goats***
	Sheep	***Laying Hens***
	Fattening Pigs	***Broilers***
	Horses	***Other Poultry***
		Sows
NOSE CODE:	**110.04.01**	**110.04.06**
	110.04.02	**110.04.07**
	110.04.03	**110.04.08**
	110.04.04	**110.04.09**
	110.04.05	**110.04.10**
		110.04.12
NFR CODE:		**N/A**

1 ACTIVITIES INCLUDED

This chapter deals with the methane emissions from animal husbandry which originate from enteric fermentation. Methane emissions from manure management are considered under SNAP code B1050.

2 CONTRIBUTION TO TOTAL EMISSIONS

Of global methane emissions, about 25 % originate from animal husbandry. These are dominated by enteric fermentation. The remaining emissions arise from rice cultivation, natural gas and oil systems, biomass burning, waste treatment, and landfills (Table 1).

Table 1a: 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.

Table 1b: 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

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 of the animals, the quality and quantity of their feed and their energy expenditure.

Ruminant breath also contains also contains dimethyl sulphide (DMS) and acetone in quantities not to be neglected.

3.2 Controls

Although the quality of the feed influences the methane emission, it is difficult to change the diet in practice for the purpose dealt with here. 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.

4 SIMPLER METHODOLOGY

The simpler approach for estimating methane emission from animal husbandry is to use one 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 (IPCC, 1997, 2000).

5 DETAILED METHODOLOGY

The detailed methodology makes use of country specific information on all the parameters involved like feed intake of the animals, digestibility or animal performance, using either the calculation procedure described as IPCC Tier 2 approach (IPCC, 1997, 2000) or emission factors derived from measurements. Also more sub-animal categories can be used than mentioned in Table 2 to reflect the fact that the herd composition may vary between countries.

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 or the FAO Production Yearbook can be used.

For the detailed methodology, matching animal numbers for cattle sub-categories, animal performance and feed characteristics are needed.

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 3. 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.

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.

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. At present the lack of sufficient information to calculate NMVOC emissions is felt to be a minor weakness.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

National total emission should be disaggregated to the appropriate territorial unit on the base of animal numbers, if emission factors and populations densities vary within the national territory.

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, thus reflecting the role of methane in atmospheric chemistry.

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 (1997, 2000).

16 VERIFICATION PROCEDURES

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

Description	Enteric fermentation			Manure management				
	SNAP Code	West Europe	East Europe	SNAP Code	West Europe		East Europe	
					cool[1]	temperate[2]	cool[1]	Temperate[2]
dairy cows	100401	100	81	100501	14	44	6	19
other cattle (young cattle, beef cattle and suckling cows)	100402	48	56	100502	6	20	4	13
sheep (adults and lambs)	100403	8	8	100505	0.19	0.28	0.19	0.28
pigs (fattening pigs, sows and piglets)	100404 & 100412	1.5	1.5	100503 & 100504	3	10	4	7
Horses	100405	18	18	100506	1.39	2.08	1.39	2.08
mules and asses	100406	10	10	100512	0.76	1.14	0.76	1.14
goats (adults and kids)	100407	5	5	100511	0.12	0.18	0.12	0.18
poultry (chicken, ducks and turkeys)	100408 - 100410	not relevant		100507 – 100509	0.078	0.117	0.078	0.117

[1] cool climate: annual average temperature less than 15° C
[2] temperature climate: annual average temperature between 15° C and 25 °C

Source: IPCC, 1997

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 Codes		**Description**	**Methane emission factors**			**Number of animals**	**Total methane emissions**
Enteric fermentation	**Manure management**		**Enteric fermentation**	**Manure management**	**Total** **A + B**		**C * D**
			A	**B**	**C**	**D**	**E**
100401	100501	dairy cows					
100402	100502	other cattle (young cattle, beef cattle and suckling cows)					
100403	100505	sheep (adults and lambs)					
100404 & 100412	100503 & 100504	pigs (fattening pigs, sows and piglets)					
100405	100506	Horses					
100406	100512	mules and asses					
100407	100511	goats (adults and kids)					
100408 – 100410	100507 - 100509	poultry (chicken, ducks and turkeys)					
		TOTAL					

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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**	**100508**
	100502	**100509**
	100503	**100510**
	100504	**100511**
	100505	**100512**
	100506	**100513**
	100507	**100514**
		100515

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

Dairy cows	***Broilers***
Other cattle	***Other poultry***
Fattening pigs	***Goats***
Sows	***Fur animals***
Sheep	***Mules and Asses***
Horses	***Camels***
Laying hens	***Buffalos***
	Other animals

NOSE CODE:	**110.05.01**	**110.05.08**
	110.05.02	**110.05.09**
	110.05.03	**110.05.10**
	110.05.04	**110.05.11**
	110.05.05	**110.05.12**
	110.05.16	**110.05.13**
	110.05.07	**110.05.14**
		110.05.15

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

1 ACTIVITIES INCLUDED

VOCs comprise both methane (CH_4) 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 unfertilized agricultural land and land fertilized with N-containing fertilizer are considered under SNAP codes 100200 and 100100 respectively.

This chapter considers the emission of methane and non-methane volatile organic compounds (NMVOCs) from the excreta of agricultural animals deposited in buildings and collected as either liquid slurry or solid manure, including 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 fertilizers) and 100200 (Cultures without fertilizers) 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).

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 with and without fertilizers and from stubble burning is very low (0.2 % for both) and almost 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.

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 stored 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 can be used 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 bio-gas plant. The produced bio-gas 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 the bio-gas generated. The latter is the most effective way, however, 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

4.1 Methane

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 of SNAP 100400 presents the recommended IPCC methane emission factors for the different classes of animals (IPCC, 1997, 2000).

4.2 Non-methane volatile organic compounds

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 definitely needed.

5 DETAILED METHODOLOGY

In their Tier 2 approach, IPCC (1997, 2000) also provide a detailed methodology for the calculation of methane emissions from manure management as a function of animal performance and the frequency distribution of animal waste storage facilities.

Calculations describing the amount of volatile solids (i.e. the amount of degradable organic material in livestock manure) have to fit the respective amounts of digestible energy needed for calculations made under SNAP code 100500. The frequency distributions of manure management systems has to coincide with the data used within SNAP code 100900.

6 RELEVANT ACTIVITY STATISTICS

For the simpler methodology, data is required on animal numbers for each of the categories listed in SNAP code 100400, 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 of the relevant sub-categories as well as matching data sets describing the excretion of volatile solids as a function of animal performance and feed, as well as the frequency distribution of the respective manure management systems.

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 SNAP 100400, Table 3. This will allow for comparability of results among all participating countries. The data and assumptions used for finer levels of detail should be reported to ensure transparency and replicability of results among all participating countries.

7 POINT SOURCE CRITERIA

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

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

9 SPECIES PROFILES

10 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 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

The detailed methodology will provide spatially resolved emission data for methane on the scale for which matching activity data and frequency distributions of storage systems and grazing times are available.

13 TEMPORAL DISAGGREGATION CRITERIA

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 (1997, 2000).

16 VERIFICATION PROCEDURES

17 REFERENCES

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