**SNAP CODES:** **100100**
**100200**

**SOURCE SUB-SECTOR TITLES:** **Cultures with Fertilizers**
**Cultures without Fertilizers**

## 1. ACTIVITIES INCLUDED

This chapter considers the ammonia emissions from the nitrogen containing fertilizers applied to agricultural soils and from the associated ammonia emissions from growing and decomposing fertilized plants.

Ammonia emissions from cultures are generally related closely to the amounts of fertilizer nitrogen applied and in most cases unfertilized cultures (SNAP code 100200) are not expected to provide significant ammonia emissions. The exception is expected to be nitrogen fixing leguminous crops, which may emit similar amounts of ammonia from foliage and decomposing leaves as other fertilized crops.

Emissions of nitrous oxide ($N_2O$) from fertilized soils are not considered in this chapter. The current edition of IPCC (1995) treats methane and in future editions nitrous oxide emissions from agricultural soils will be discussed.

Ammonia emissions following slurry application or from grazing of grass swards are considered in SNAP code 100500.

## 2. CONTRIBUTION TO TOTAL EMISSIONS

The major source of ammonia emissions in Europe is the volatilization of livestock excretions, however 10-20% of the emissions are estimated to derive from the volatilization of nitrogenous fertilizers and from fertilized crops. Example estimates of total ammonia emissions in Europe are given in Table 1 of SNAP code 100500.

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

| **Source-activity** | **SNAP-code** | **Contribution to total emissions [%]** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $SO_2$ | $NO_x$ | NMVOC | $CH_4$ | CO | $CO_2$ | $N_2O$ | $NH_3$ |
| Cultures with Fertilizers | 100100 | - | - | 0.2 | 1.0 | - | - | 9.5 | 4.0 |
| Cultures without Fertilizers | 100200 | - | - | - | - | - | - | - | - |

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

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

The estimates of ammonia emission from decomposing agricultural cultures are also extremely uncertain, and emissions from this source are likely to be very variable. The limited experimental data (Whitehead and Lockyer, 1989) found only emission from foliage with a high nitrogen content where much fertilizer had been applied, and was restricted to laboratory measurements which may overestimate emission. For unfertilized cultures (with the exception of legumes), significant emissions from this source are not expected.

Emissions of ammonia from mineral fertilizers depend on the type of fertilizer applied, soil type (especially soil pH), meteorological conditions and time of application in relation to a crop canopy. In particular, the type of fertilizer applied has a great effect on the magnitude of emissions (Whitehead and Raistrick, 1990). Emissions are largest from urea fertilizer because it hydrolyses in the soil and releases ammonia. Emissions from ammonium sulphate may also be large, but these are very dependent on soil pH, with larger emissions from calcareous soils. Other fertilizers, such as ammonium nitrate are more neutral in pH and show much smaller emissions, which are often difficult to distinguish in measurements from plant-atmosphere fluxes.

Depending on the interpretation of results, emissions from growing vegetation and from decomposing grass herbage may be treated as additional emissions to soil emissions, or may be included together 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 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., 1995). 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 ammonia emissions and deposition occur on diurnal cycles, and it has been suggested that for some arable ecosystems, on an annual basis foliar emissions may balance dry deposition to the same vegetation (Sutton et al., 1995). Foliar emissions are expected to be larger from annual cereal crops than for fertilized agricultural grassland, since much of the emission may occur during the grain ripening and vegetation senescence phase (Schjrrring, 1991). In contrast, where agricultural grassland is 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.

### 3.2 Controls

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

However, there may be potential for reducing crop emissions by switching from urea to other fertilizers. Urea contributes approximately 50% of the fertilizer ammonia emissions in western Europe (ECETOC, 1994) because of its higher volatilization rate. A potentially effective control of fertilizer emissions would therefore be to use alternative fertilizers with smaller ammonia 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. However, it should also be noted that urease inhibitors may have other undesirable environmental effects which need to be assessed before these are recommended.

As ammonia emissions from cultures are strongly a function of nitrogen supply, another potential control is to use cultivars or crop species which require less nitrogen. Use of less nitrogen 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 reductions in fertilizer N inputs where these have an additional benefit for other environmental effects, such as reducing nitrate leaching.

Fertilizer application can be done by placing the fertilizer granule into the soil at a depth of 7-8 cm together with the seed (cultivation of cereals, reseeding of pastures). The ammonia emissions from this kind of application of fertilizers have been estimated to be negligible (assuming that nitrogen supply is dimensioned correctly). Deep placement of fertilizer granules is common technology and has been used for many years in Finland.

It should be noted that none of these changes have so far been applied by countries as measures to limit ammonia emissions, and further work would be required to provide a detailed evaluation of these possibilities.

## 4. SIMPLER METHODOLOGY

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 nitrogen use for each of the main fertilizer categories. In the simplest methodology the % N emission 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 simpler methodology are provided in Table 2. These are based largely on the estimates of Asman (1992), ECETOC (1994) and Sutton et al. (1995). 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 2). In contrast the estimates here are larger than the estimates of Sutton et al. (1995).

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

To calculate ammonia emissions from cultures in a country, the use of each fertilizer type (expressed as mass N used per year), is multiplied by the appropriate emission factor, and the emissions for the different fertilizer types summed. A simple spreadsheet for this calculation is provided in the detailed methodology (see section 5).

**Table 2: Simpler methodology estimates of total emissions from cultures due to fertilizer volatilization, foliar emissions and decomposing vegetation (second column). The estimates are compared with other literature values. Values are % volatilization of N in fertilizers applied (100 * $NH_3$-N/fertilizer N)**

| **Fertilizer type** | **Present simpler methodology to apply** | **Asman (1992) (Europe)** | **ECETOC (1994) Group II European countries)** | **Sutton et al. (1995) (UK)** |
|---|---|---|---|---|
| Emissions from | fertilizer and plants | fertilizer | fertilizer | fertilizer and plants |
| Ammonium sulphate | 8 | 8 | 10 | - |
| Ammonium nitrate | 2 | 2 | 2 | 1 |
| Calcium ammonium nitrate | 2 | 2 | 2 | 1 |
| Anhydrous ammonia | 4 | 1 | 4 | - |
| Urea | 15 | 15 | 15 | 10 |
| Combined ammonium phosphates (generally di-ammonium phosphate) | | 4 | 5 | - |
| Mono-ammonium phosphate | 2 | | | |
| Di-ammonium phosphate | 5 | | | |
| Other complex NK, NPK fert | 2 | 2.5 - 4 | 2 | 2.5 |
| Nitrogen solutions (mixed urea and ammonium nitrate) | 8 | - | 8 | - |

## 5. DETAILED METHODOLOGY

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

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

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

Values of emission estimates for the more detailed methodology are provided in Table 3. A simple spreadsheet is provided for calculating culture ammonia emissions in Table 4.

A further minor source not treated by this approach is emission of ammonia from unfertilized nitrogen fixing legumes. The available measurements suggest both emission and deposition of ammonia from legumes (see Sutton et al., 1993; Holtan-Hartwig and Brckman, 1994), though in general there is likely to be a small net emission of similar magnitude to foliar emissions from fertilized crops. Where data are available on the areas of legumes under cultivation and the extent of typical nitrogen fixation by each crop type, national ammonia emission from this source may be approximately estimated as:

Legume emission = sum all legume species {0.01 * species N fixation * area of species}

(kg N per year) = (kg N per ha.year) * (ha)

Where information on average nitrogen fixation rates for different legume species is unavailable for a country, 100 kg N per ha per year may be used as a first estimate. Ammonia emissions from legumes are included for completeness, though they will only represent a minor component of culture ammonia emissions.

A potential overestimation of ammonia emissions from cultures may result using both the simple and detailed methodology as outlined above, resulting from the possible double counting of emission from fertilized grazed pastures. The experiments which have defined rates of ammonia emission from grazing animals have been made over swards supplied with different amounts of nitrogen as ammonium nitrate or complex fertilizers. Hence emissions from these fertilizers with only a limited volatilization rate (see Table 4) or from foliar emissions are already implicitly treated in the estimation of grazing emissions. Nevertheless, there is current debate as to whether these emissions should be treated separately anyway, because grazing and fertilization frequently occur at diferent times of the year. The argument concerns the temporal distribution of the resulting fertilizer and foliar emissions, and whether these are of short duration during ungrazed periods, or are mediated over a much longer time when the animals are grazing. It should be noted that no correction would need to be applied for fertilized, ungrazed grasslands.

Should it be considered that fertilization and crop ammonia emissions occur over longer periods overlapping with grazing periods, a correction to the cultures emissions factors for grazed grassland is required. The basis for this is described in section 12.

**Table 3: Detailed methodology estimates of total ammonia emissions from cultures due to fertilizer volatilization, foliar emissions and decomposing vegetation. Values are % volatilization of N in fertilizers applied (100 * $NH_3$-N/fertilizer N)**

| **Fertilizer type** | **Group I** | **Group II** | **Group III** |
|---|---|---|---|
| Ammonium sulphate | 15 | 10 | 5 |
| Ammonium nitrate | 3 | 2 | 1 |
| Calcium ammonium nitrate | 3 | 2 | 1 |
| Anhydrous ammonia | 4 | 4 | 4 |
| Urea | 20 | 15 | 15 |
| Combined ammonium phosphates (generally di-ammonium phosphate) | 5 | 5 | 5 |
| Other complex NK, NPK fertilizers | 3 | 2 | 1 |
| Nitrogen solutions (mixed urea and ammonium nitrate) | 8 | 8 | 8 |

## 6. RELEVANT ACTIVITY STATISTICS

Information is required on the annual consumption of major nitrogen fertilizer types by each country. This information may be found from IFA (1992) as well as from national agricultural censuses.

Where spatially disaggregated inventories of cultures emissions of ammonia are required (section 12), information on the spatial distribution of different crop types and average fertilizer inputs to each crop type may be used. In the absence of data on use of different fertilizers for crop types, the average fertilizer inputs to crops may be combined with the average ammonia emission factor for a country estimated according to Table 4 as: Total $NH_3$ emission/total fertilizer N consumption.

## 7. POINT SOURCE CRITERIA

Ammonia emission from cultures should be treated as area sources.

## 8. EMISSION FACTORS, QUALITY CODES AND REFERENCES

The emission factors for ammonia losses from cultures are treated as a percentage of N applied as fertilizer or, in the case of nitrogen fixing crops (unfertilized), as a percentage of the nitrogen fixed. Full details of calculations are provided in sections 5 and 6.

**Table 4: Spreadsheet for calculating culture ammonia emissions according to either the simpler or more detailed methodologies**

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

## 9. SPECIES PROFILES

## 10. UNCERTAINTY ESTIMATES

Although the processes governing the emission of ammonia from fertilizers and crops are reasonably well understood, the interactions of many biological, chemical and environmental factors make quantitative estimates of emission rather uncertain. The main uncertainty lies in the generalization of emissions factors, rather than the areas of crops under cultivation which is probably accurate in most countries to better than +/- 10 %. For example, the ranges of uncertainty for Group II emission factors in Table 2 are probably wider than the figures given as emission factors for Groups I and III, which are included in order to avoid bias between countries with different conditions. Overall culture emissions are probably no better than +/- 50 %.

## 11. WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

A major criticism of the present estimates is their reliance on simple fixed (%) emission factors, given in relation to amounts of nitrogen applied. A first attempt to account for broad scale difference between countries (based on climate and soil type) has been included here (detailed methodology) but it is very much an empirical interpretation of the available data. More work needs to be done in the development of mechanistic process based models for predicting ammonia emissions from fertilizers and the foliage of fertilized crops, which take into account the known physicochemical equilibria as well as interactions with biological processes to predict net fluxes. It is well established that ammonia 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.

The current estimates are limited to net emission of ammonia 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.

## 12. SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

The simplest approach to spatially disaggregate the emissions from cultures 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 3. Where the average fertilizer application to crops is derived from similar national data as the fertilizer consumption, there should be a reasonable match up 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). If this effect is to be treated in spatially disaggregating emissions, it may be considered that the emissions from grazed grass, where this is supplied fertilized with ammonium nitrate or complex fertilizers, are already included in the grazing emissions. In this case, land-use maps of grazed grassland would be required, in a similar way to the distribution of crop types, but here a reduced emission factor applied to account for only emissions from 'high emissions' fertilizers. This reduced overal emissions factor may be found by completing a version of Table 3 for grazed grassland, not including emissions from ammonium nitrate, calcium ammonium nitrate or other complex fertilizers. Dividing the total ammonia emission by total N fertilizer use, multiplied by 17/14, provides an 'average' % N nitrogen volatilized for grazed grassland. This can then be applied with the mapped distribution of grazed grassland. Where only the distribution of total grassland is available estimates would need to be made of the fraction that is grazed, while account of the temporal overlap of grazing and culture emission should also be taken.

## 13. TEMPORAL DISAGGREGATION CRITERIA

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

## 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 national fertilizer consumption, and, where disaggregated estimates are to be made, details on N application rates to crops and spatially disaggregated crop distributions.

## 16. VERIFICATION PROCEDURES

There are no direct methods to evaluate total inventory estimates of ammonia 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 ammonia fluxes over a range of crop types in different climates.

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## 18. BIBLIOGRAPHY

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

## 19. RELEASE VERSION, DATE AND SOURCE

| | |
|---|---|
| Version: | 3.0 |
| Date: | November 1995 |
| Source: | Mark Sutton<br>Institute of Terrestrial Ecology (Edinburgh Research Station)<br>Bush Estate, Penicuik<br>Midlothian, EH26 OQB, UK. |

## SNAP CODE: 100300

## SOURCE SUB-SECTOR TITLE: Stubble Burning

## 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 emissions [%] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $SO_2$ | $NO_x$ | 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 by 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 calculating emissions 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 statistic is the amount (dry weight) of waste/residue combusted.

## 7. POINT SOURCE CRITERIA

## 8. EMISSION FACTORS, QUALITY CODES 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. UNCERTAINTY ESTIMATES

No uncertainty estimates have been quantified but it is likely that the emission factors have a high uncertainty as emissions of $NH_x$ depend very much upon combustion conditions, i.e. a lower-temperature smouldering combustion will release more $NH_x$ than a high temperature flame.

## 11. WEAKEST ASPECTS/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 $CH_4$, 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 emissions from agricultural waste combustion. Geophysical Research Letters 21, 281-284.

## 18. BIBLIOGRAPHY

## 19. RELEASE VERSION, DATE AND SOURCE

Version: 2.0

Date: September 1995

Source: Dr David S. Lee
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**SNAP CODE :** **100400**

**SOURCE SUB-SECTOR TITLE :** **Enteric Fermentation**

## 1. ACTIVITIES INCLUDED

Activities included are:

| | | | |
|---|---|---|---|
| 100401 | Dairy Cows | 100405 | Horses |
| 100402 | Other Cattle | 100406 | Mules and Asses |
| 100403 | Ovines | 100407 | Goats |
| 100404 | Fattening Pigs | | |

This chapter deals with the methane emissions from animal husbandry. Two sources of methane emission are distinguished: enteric fermentation of agricultural animals and animal waste management. Ammonia emissions from animal husbandry is considered in chapter B1050.

## 2. CONTRIBUTION TO TOTAL EMISSIONS

From the global methane emissions about 25% originates from animal husbandry. The remaining emissions arise from rice cultivation, natural gas and oil systems, biomass burning, waste treatment, landfills and from mining, transportation and combustion of coal.

Estimated values for the methane emissions from European and world wide animal husbandry are presented in Table 1. The European animal husbandry is responsible for approximately 7% of the global methane emissions.

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

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

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

CORINAIR 1990 provide some alternative estimates of European emissions.

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

| Source-activity | SNAP-code | Contribution to total emissions [%] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $SO_2$ | $NO_x$ | NMVOC | $CH_4$ | CO | $CO_2$ | $N_2O$ | $NH_3$ |
| Enteric Fermentation | 100400 | - | - | - | 20.5 | - | - | - | 0.5 |

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

## 3. GENERAL

### 3.1 Description

**Enteric fermentation**

Methane is produced in herbivores as a 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 animal, the quality and quantity of the feed and the energy expenditure of the animal.

**Animal waste management**

Methane is produced from the decomposition of organic components in animal waste. The amount of released methane depends on the quantity of waste produced and the portion of the waste that decomposes anaerobically. When the animal waste is 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.

### 3.2 Controls

**Enteric fermentation**

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

**Animal waste management**

There are two strategies to decrease the methane emissions from animal wastes.

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

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

## 4. SIMPLER METHODOLOGY

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

## 5. DETAILED METHODOLOGY

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

## 6. RELEVANT ACTIVITY STATISTICS

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

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

## 7. POINT SOURCE CRITERIA

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

## 8. EMISSION FACTORS, QUALITY CODES AND REFERENCES

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

**Table 2:** **Methane emission factors for simpler methodology**

**annually averaged emission in kg $CH_4$ per animal, as counted in the annual agricultural census**

| SNAP code | description | enteric fermentation | | manure management | | | |
|---|---|---|---|---|---|---|---|
| | | west Europe | east Europe | west Europe | | east Europe | |
| | | | | cool[1] | temperate[2] | cool[1] | temperate[2] |
| 100401 | dairy cows | 100 | 81 | 14 | 44 | 6 | 19 |
| 100402 | other cattle (young cattle, beef cattle and suckling cows) | 48 | 56 | 6 | 20 | 4 | 13 |
| 100403 | pigs (fattening pigs, sows and piglets) | 1.5 | 1.5 | 3 | 10 | 4 | 7 |
| 100404 | sheep (adults and lambs) | 8 | 8 | 0.19 | 0.28 | 0.19 | 0.28 |
| 100405 | goats (adults and kids) | 5 | 5 | 0.12 | 0.18 | 0.12 | 0.18 |
| 100406 | horses | 18 | 18 | 1.39 | 2.08 | 1.39 | 2.08 |
| 100407 | mules and asses | 10 | 10 | 0.76 | 1.14 | 0.76 | 1.14 |
| 100408 | poultry (chickens, ducks and turkeys) | not estimated | | 0.078 | 0.117 | 0.078 | 0.117 |

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

[2] temperate climate: annual average temperature between 15E and 25E C

Source: IPCC, 1995

**Table 3:** **Total methane emissions based on methane emission factors and animal class numbers**

**Emission factors in kg $CH_4$ per animal, as counted in the annual agricultural census**

| **SNAP code** | **description** | **methane emission factor** | | | **number of animals** | **total methane emission** C * D |
|---|---|---|---|---|---|---|
| | | **enteric fermentation** | **manure management** | **total** A + B | | |
| | | **A** | **B** | **C** | **D** | **E** |
| 100401 | dairy cows | | | | | |
| 100402 | other cattle (young cattle, beef cattle and suckling cows) | | | | | |
| 100403 | pigs (fattening pigs, sows and piglets) | | | | | |
| 100404 | sheep (adults and lambs) | | | | | |
| 100405 | goats (adults and kids) | | | | | |
| 100406 | horses | | | | | |
| 100407 | mules and asses | | | | | |
| 100408 | poultry (chickens, ducks and turkeys) | | | | | |
| | TOTAL | | | | | |

## 9. SPECIES PROFILES

## 10. CURRENT UNCERTAINTY ESTIMATES

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

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

## 11. WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

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.

## 12. SPATIAL DISSAGGREGATION CRITERIA FOR AREA SOURCES

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

## 13. TEMPORAL DISSAGGREGATION CRITERIA

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

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

## 14. ADDITIONAL COMMENTS

## 15. SUPPLEMENTARY DOCUMENTS

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

## 16. VERIFICATION PROCEDURES

## 17. REFERENCES

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## 18. BIBLIOGRAPHY

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

## 19. RELEASE VERSION, DATE AND SOURCE

| | |
|---|---|
| Version: | 2.0 |
| Date: | November 1995 |
| Source: | Klaas Van Der Hoek<br>RIVM, Bilthoven<br>The Netherlands |

**SNAP CODE :** **100500**

**SOURCE SUB SECTOR TITLE :** **Manure Management**

## 1. ACTIVITIES INCLUDED

Activities included are:

| | | | |
|---|---|---|---|
| 100501 | Dairy Cows | 100506 | Horses |
| 100502 | Other Cattle | 100507 | Laying Hens |
| 100503 | Fattening Pigs | 100508 | Broilers |
| 100504 | Sows | 100509 | Other Poultry |
| 100505 | Ovines | 100510 | Fur Animals |

This chapter considers ammonia emissions from the excreta of agricultural animals. This includes emissions from animal excreta at all stages: animal housing, slurry and manure storage, grazing animals and from land spreading of animal wastes.

Ammonia emissions from fertilizer application is chapter B1010 together with nitrous oxide emissions from fertilizer application and spreading of animal wastes. Methane emissions from enteric fermentation and storage of animal wastes are considered in chapter B1040.

## 2. CONTRIBUTION TO TOTAL EMISSIONS

As a rough estimate, 80-95% of the total ammonia emissions in Europe originates from agricultural practices, the remainder is contributed by industrial sources, households, pet animals and natural ecosystems.

Ammonia emissions from animal excreta contribute over 80% and emissions from application of fertilizers contribute less than 20% of the total ammonia emissions of agricultural origin in Europe in 1989 (Asman, 1992). There is however a large variation from country to country and also a wide variation in ammonia emission 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. By using only one average emission factor per main animal category, country specific differences in nitrogen excretion by livestock and differences in farming situations are not accounted for.

The contribution of the sub-sector to CORINAIR 1990 emission for Europe was as follows.

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

| Source-activity | SNAP-code | Contribution to total emissions [%] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $SO_2$ | $NO_x$ | NMVOC | $CH_4$ | CO | $CO_2$ | $N_2O$ | $NH_3$ |
| Dairy Cows | 100501 | - | - | 0.1 | 1.9 | - | 0 | 0.2 | 25.1 |
| Other Cattle | 100502 | - | - | 0.1 | 2.4 | - | 0 | 0.4 | 21.5 |
| Fattenig Pigs | 100503 | - | - | 1.3 | 3.0 | - | 0 | 0.2 | 10.6 |
| Sows | 100504 | - | - | 0.1 | 0.6 | - | 0.1 | - | 3.4 |
| Ovines | 100505 | - | - | 0 | 0.5 | - | 0 | 0.1 | 5.5 |
| Horses | 100506 | - | - | 0 | 0.2 | - | - | - | 1.0 |
| Laying Hens | 100507 | - | - | 0 | 0.3 | - | - | - | 2.5 |
| Broilers | 100508 | - | - | 0 | 0.2 | - | - | - | 1.8 |
| Other Poultry | 100509 | - | - | 0 | 0.1 | - | - | - | 0.6 |
| Fur Animals | 100510 | - | - | - | 0 | - | - | - | 0.2 |

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

Ammonia emissions from animal husbandry occur from both housed and grazing animals. 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 wastes.

Ammonia emissions from livestock depend on many factors including:

- the nitrogen content of the feed;
- the conversion of nitrogen in feed to nitrogen in meat, milk and eggs, and hence the amount of nitrogen in the animal wastes;
- the species, age and weight of the animal;
- the housing system of the animal, including storage of the wastes inside the building;
- the storage system of the waste outside the building: open or covered slurry tank, loose or packed pile of solid wastes;
- climatic conditions in the building and the storage system like temperature;
- the proportion of time spent by animals indoors and in the meadows.

**Table 1: Percentage contributions of ammonia emissions of agricultural origin**

| | average contribution on European scale[1] | range for individual countries[2] | The Netherlands[3] | United Kingdom[4] |
|---|---|---|---|---|
| *year* | *1989* | *1989* | *1990* | *1988* |
| animal excreta | 83% | 68 - 95% | 95% | 92% |
| - cattle | 55% | 21 - 83% | 54% | 61% |
| - sheep | 5% | 0 - 35% | 2% | 10% |
| - pigs | 15% | 0 - 41% | 31% | 10% |
| - poultry | 6% | 0 - 10% | 8% | 11% |
| application of fertilizer | 17% | 5 - 32% | 5% | 8% |

[1] and [2] Asman, 1992
[3] Van Der Hoek, 1994
[4] Sutton et al, 1995

Ammonia emissions from animal wastes after spreading depend on:

- properties of the animal wastes including dry matter and ammoniacal nitrogen content, viscosity 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 windspeed;
- the method and rate of application of animal wastes, including, for arable land, the time between application and ploughing;
- height of the crop (grassland).

In order to calculate ammonia emissions precisely it would be 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.

## 3.2 Controls

There are a number of potential methods of 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 fertilizer and does not cause other environmental problems such as nitrate leaching or nitrous oxide emissions.

A wide range of control techniques may be applied to reduce ammonia emissions, depending on the source type and existing management practices. The most widely used approaches for reducing ammonia emissions from livestock include low emission land spreading techniques and covering of slurry storage tanks. Low emission land spreading techniques include turf impregnation and injection of slurries (to grassland) and directly ploughing in or harrowing animal wastes after its application to arable land. In The Netherlands legislation already exists for land spreading of animal wastes, which came into force in September 1991 (Besluit gebruik dierlijke meststoffen, 1991).

If applied carefully low emission techniques such as injection give about 80% reduction in ammonia emission on grassland, compared to surface spreading of animal wastes. However injection techniques are not suitable for stony or sloping fields, or in all weather conditions. In addition, deep injection of slurries may increase nitrate leaching from soils if the amount of nitrogen fertilizer is not adjusted with the conserved nitrogen in ammonia emission.

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.

Covering the slurry storage tank outside the building with a tight roof decreases the emission of ammonia by 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 include modified housing conditions. Examples are fast removal of urine in cubicles for cattle, keeping the temperature of stored pig manure in pig stables below 15 EC, belt drying of manure from laying hens inside the poultry house and drying of wastes from broilers inside the building. 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.

Animal feeding strategies can also be used for reducing ammonia emissions. A better adjustment of protein supply in the feed and protein requirement of the animal results in a lower nitrogen excretion. The achievable reduction of ammonia emission is lower than with modification of the housing systems, but the associated costs are also much lower.

## 4. SIMPLER METHODOLOGY

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 with the number of animals counted in the annual agricultural census. Table 2 presents the recommended default 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 stable and also volatilization factors for the remaining nitrogen entering the storage outside the building and for the nitrogen available for landspreading. The appendix gives more details and also instructions on how to account for emission control techniques.

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

## 5. DETAILED METHODOLOGY

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. Volatilization percentages can also be based on measurements of ammonia emissions from stables, storages and land application of wastes. Also more sub-animal categories can be used than mentioned in Table 2. Besides the ammonia emissions can be estimated for regions within a country with equal climatic conditions or soil properties.

Once emissions have been calculated at whatever is determined by the national experts to be the most appropriate level of detail, results should also be aggregated up to the minimum standard level of information as given in Table 2. This will allow for comparability of results among all participating countries. The data and assumptions used for finer levels of detail should also be reported to ensure transparency and replicability of methods.

## 6. RELEVANT ACTIVITY STATISTICS

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

For the detailed methodology, the same data is required on animal numbers. In addition information is needed for all the parameters mentioned in section 5 (see also the appendix).

## 7. POINT SOURCE CRITERIA

Emissions of ammonia should be considered on an area basis.

## 8. EMISSION FACTORS, QUALITY CODES AND REFERENCES

Ammonia emissions from animal husbandry can be split up into emissions from housing, storage of animal wastes, grazing and application of animal wastes. Table 2 presents for each class of animal the default ammonia emission factors when the animal wastes are surface spread. Using low emission techniques for application of the animal wastes results in a lower emission factor. When both application techniques are applied, the revised emission factor is calculated by taking the weighted average of both forms of wastes application.

The (revised) emission factors can be inserted into Table 3, a blank version of Table 2. The new table calculates animal class emission factors and these are combined with animal numbers to give total ammonia emissions for a country.

## 9. SPECIES PROFILES

## 10. CURRENT UNCERTAINTY ESTIMATES

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%.

## 11. WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

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. In addition differing situations with regard to soil characteristics and temperature are also not taken into account.

The detailed methodology is based on ammonia emission factors for individual countries or representative areas of Europe.

## Table 2: Ammonia emission factors for simpler methodology

**annually averaged emission in kg $NH_3$ per animal, as counted in the annual agricultural census**

| SNAP code | description | stable | storage outside the stable | surface spreading of waste | grazing | total emissions |
|---|---|---|---|---|---|---|
| 100501 | dairy cows | 8.7 | 3.8 | 12.1 | 3.9 | 28.5 |
| 100502 | other cattle (including young cattle, beef cattle and suckling cows) | 4.4 | 1.9 | 6.0 | 2.0 | 14.3 |
| 100503 | fattening pigs | 2.89 | 0.85 | 2.65 |  | 6.39 |
| 100504 | sows[1] | 7.43 | 2.18 | 6.82 |  | 16.43 |
| 100505 | sheep (sheep and goats)[1] | 0.24 |  | 0.22 | 0.88 | 1.34 |
| 100506 | horses (horses, mules and asses) | 2.9 |  | 2.2 | 2.9 | 8.0 |
| 100507 | laying hens (laying hens and parents) | 0.19 | 0.03 | 0.15 |  | 0.37 |
| 100508 | broilers (broilers and parents) | 0.15 | 0.02 | 0.11 |  | 0.28 |
| 100509 | other poultry (ducks, geese, turkeys) | 0.48 | 0.06 | 0.38 |  | 0.92 |
| 100510 | fur animals[1] | 0.60 |  | 1.09 |  | 1.69 |

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

**See the Appendix for an explanation how to use these default emission factors**

**Table 3:** **Total ammonia emissions based on ammonia emission factors and animal class numbers**

**Emission factors in kg $NH_3$ per animal, as counted in the annual agricultural census**

| SNAP code | description | ammonia emission factor | | | | | number of animals | total ammonia emission E * F |
|---|---|---|---|---|---|---|---|---|
| | | stable | storage | application | grazing | total A+B+C+D | | |
| | | A | B | C | D | E | F | G |
| 100501 | dairy cows | | | | | | | |
| 100502 | other cattle (including young cattle, beef cattle and suckling cows) | | | | | | | |
| 100503 | fattening pigs | | | | | | | |
| 100504 | sows (only female adult animals) | | | | | | | |
| 100505 | sheep (only female adult sheep and goats) | | | | | | | |
| 100506 | horses (horses, mules and asses) | | | | | | | |
| 100507 | laying hens (laying hens and parents) | | | | | | | |
| 100508 | broilers (broilers and parents) | | | | | | | |
| 100509 | other poultry (ducks, geese, turkeys) | | | | | | | |
| 100510 | fur animals (only female adult animals) | | | | | | | |
| | TOTAL | | | | | | | |

## 12. SPATIAL DISSAGGREGATION CRITERIA FOR AREA SOURCES

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

## 13. TEMPORAL DISSAGGREGATION CRITERIA

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

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

## 14. ADDITIONAL COMMENTS

## 15. SUPPLEMENTARY DOCUMENTS

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 the appendix (Van Der Hoek, 1995).

For the detailed methodology the documents of ECETOC (1994), the UNECE Working Group on Technology (Haanstra, 1995) and the MARACCAS model (ApSimon et al, 1995) can be useful.

## 16. VERIFICATION PROCEDURES

## 17. REFERENCES

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Van Der Hoek, K.W., 1996. Ammonia emission factors for European agriculture. Paper in preparation for Atmospheric Environment.

## 18. BIBLIOGRAPHY

## 19. RELEASE VERSION, DATE AND SOURCE

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Klaas Van Der Hoek
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## *APPENDIX*

### EXPLANATION OF THE AMMONIA EMISSION FACTORS USED IN THE SIMPLER METHODOLOGY

This appendix presents the calculation scheme for emissions of ammonia. The calculation starts with the average nitrogen excretion of the animal. Ammonia losses during housing, storage of wastes outside the building, grazing and application of wastes are calculated as a volatilization percentage of the 'incoming' amount of nitrogen. This means that when for example a slurry storage tank is covered, the volatilization percentage declines and the amount of nitrogen available for landspreading increases and consequently the emission of ammonia also increases.

The volatilization percentages for stables are derived from the Dutch ammonia emission factors for stables. These emission factors are based on measurements during the winter season for dairy cattle and during a full year for pigs and poultry. The volatilization percentages for slurry storage tanks, grazing 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 2. The underlying data for these ammonia emission factors are presented in Table 4. 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 volatilization percentage has to be multiplied with 0.2.

## 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 fertilizer 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 fertilizer. 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 stable. 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 stable for milking and so, so it is assumed that 20% of the excreted nitrogen is collected in the stable. Effectively 40 kg of nitrogen are excreted in the pasture and 60 kg in the stable.

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 of the stable is likely to be lower but the emission of the farmyard manure pile is higher. For the present it is assumed that emissions of ammonia are equal to slurry based 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.

## 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, nitrogen excretion 46 kg (stable 24 kg and pasture 22 kg)
- 10% suckling cows, nitrogen excretion 80 kg (stable 35 kg and pasture 45 kg)
- 15% beef cattle housed all year, nitrogen excretion 40 kg.

This results in an average nitrogen excretion of 50 kg pro animal, of which 30 kg in the stable and 20 kg on pasture. The figures in Table 4 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 4 are based on an 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 4 are meant as an average for adult as well as for young animals.

## PIGS AND POULTRY

As far as these animals are kept in stables, 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.

For all animal categories in Table 4 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 stable between two consecutive 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 higher (a loose pile gives high emissions). Total emissions of ammonia are assumed to be the same for slurry based and solid manure based systems.

Table 4 presents calculations for fattening pigs and for a sow with her adherent 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 2 and 3 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 (older than 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 it is more complex to make a subdivision. A very rough estimation is 45% 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 4: Ammonia emission factors for animal husbandry

| | ratio[1] | kg N | kg $NH_3$ | ratio[1] | kg N | kg $NH_3$ |
|---|---|---|---|---|---|---|
| | *100501 dairy cows* | | | *100502 other cattle* | | |
| N excretion in stable | | 60.00 | | | 30.00 | |
| emission in stable | 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 |
| N excretion in meadow | | 40.00 | | | 20.00 | |
| emission in meadow | 8% | 3.20 | 3.9 | 8% | 1.60 | 2.0 |
| | *100503 fattening pigs* | | | *100504 sows[3]* | | |
| N excretion in stable | | 14.00 | | | 36.00 | |
| emission in stable | 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 |
| N excretion in meadow | | | | | | |
| emission in meadow | | | | | | |
| | *100505 sheep[3]* | | | *100506 horses* | | |
| N excretion in stable | | 2.00 | | | 20.00 | |
| emission in stable | 10% | 0.20 | 0.24 | 12% | 2.40 | 2.9 |
| N in outside storage | | 1.80 | | | 17.60 | |
| emission in outside storage | | | | | | |
| 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 |
| N excretion in meadow | | 18.00 | | | 30.00 | |
| emission in meadow | 4% | 0.72 | 0.88 | 8% | 2.40 | 2.9 |

| | *100507 laying hens* | | | *100508 broilers* | | |
|---|---|---|---|---|---|---|
| N excretion in stable | | 0.80 | | | 0.60 | |
| emission in stable | 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 |
| N excretion in meadow | | | | | | |
| emission in meadow | | | | | | |
| | *100509 other poultry* | | | *100510 fur animals[3]* | | |
| N excretion in stable | | 2.00 | | | 4.10 | |
| emission in stable | 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 |
| N excretion in meadow | | | | | | |
| emission in meadow | | | | | | |

[1] ratio N volatilized as $NH_3$-N / N in animal waste

[2] N in animal waste consists of mineral N (available for volatilization) 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.