Working Paper

EMISSIONS OF AMMONIA IN EUROPE

Ger Klaassen

WP—90—68
November 1990

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Foreword

Nitrogen deposition from ammonia emissions is an important factor in regional acidification, eutrophication and other undesirable environmental effects in Europe. Strategies to reduce nitrogen emission in Europe must include efforts to reduce ammonia emissions. During the past several years the Transboundary Air Pollution Project (TAP) has been expanding the Regional Acidification INformation and Simulation (RAINS) model to include nitrogen compounds. The work on oxides of nitrogen is well underway; during the past year we have turned our attention increasingly to ammonia including a detailed assessment of its sources, and the cost of controlling its emissions. Ger Klaassen from the Free University of Amsterdam, joined TAP to spearhead our work in ammonia; this Working Paper represents a considerable effort in quantifying European emissions of ammonia.

Bo R. Döös
Leader, Environment Program

Roderick W. Shaw
Leader, Transboundary Air Pollution Project

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Abstract

The ammonia emissions of the RAINS (Regional Acidification INformation and Simulation) model are presented. Sources of ammonia considered are livestock farming, fertilizers, industry, human population and other anthropogenic sources. In contrast to previous studies emission factors are country specific, accounting for differences in stall period and fertilizer level, using recent data on emission coefficients in the Netherlands. Moreover, other sources such as dairy cows and human populations, are included. Ammonia emissions in 1980 in 26 European countries and Turkey are estimated at 7045 kilotons. That is 10 per cent higher than Buijsman (1987) estimated. Ammonia emissions in 1987 are 7205 kilotons and 15 per cent lower than a recent study by Asman (1990) indicated. RAINS estimates are in line with various national estimates.

Contents

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Ger Klaassen[2]

1. INTRODUCTION

Acidification of the environment caused by atmospheric deposition is one of the serious environmental problems in Europe. In addition to sulphur compounds, nitrogen compounds contribute to acidification in the form of nitrogen oxides (NO_x) and ammonia (NH_3). Ammonia contributes more than 40 per cent to the total anthropogenic emissions of nitrogen in Europe. The share of ammonia in the total nitrogen deposition in Europe may even be higher in specific regions and varies between 30 and 90%.

NH_3 can cause both direct and indirect effects on the environment. Direct effects can occur if vegetation is exposed to high concentrations in the air over long periods of time (Ministry of Housing, Physical Planning and Environment, 1986). This mainly takes places in the direct vicinity of NH_3 sources. The damage resulting from ammonia usually has an indirect cause in which four different mechanisms can play a role:

1. Acidification of soils, and eventually groundwater, through conversions of NH_3 via ammonium into nitrate,
2. Supplanting of nutrient ions such as magnesium and calcium by ammonium resulting in a shortage of these ions for the plant,
3. Eutrophication of nutrient poor regions. Consequently, many plant species characteristic of poorly buffered environments may disappear (Roelofs et al, 1987),

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4. NH_3 promotes the deposition of SO_2 because, for example, tree needles become basic due to NH_3 deposition. Because basic needles react more strongly than acid needles to SO_2 a higher SO_2 deposition takes place.

The Regional Acidification Information and Simulation (RAINS) model developed at IIASA combines information on several stages of the acidification processes in the environment: the sources of emissions and the potential for their abatement, the atmospheric transport and the environmental effects of acid deposition. These impacts are evaluated on a regional scale for the whole of Europe for forests stands, forest soils and lakes. In doing so the model includes the pathways of the main precursors of acidification: SO_2, NOx and NH_3. So far however no explicit sub module has been incorporated into RAINS which describes the sources of ammonia emissions and their development over time.

This paper describes the design for the NH_3 emission module as it will be incorporated in RAINS. In addition, the data on emission coefficients are presented and elucidated and some preliminary results are shown.

The remainder of the paper is organized as follows. Section 2 describes the overall set up and algorithm. Section 3 presents the emission coefficients for livestock farming and Section 4 the coefficients of nitrogen fertilizer. Industrial emission coefficients and the emissions of human population and other sources are explained in Section 5. Section 6 presents calculations of the NH_3 emissions in Europe in 1980 and 1987 and compares RAINS estimates with other estimates.

2. THE EMISSION MODULE

Ammonia emissions in Europe originate from the following sources:

1. livestock farming (animal manure):
   - stalls and manure storage,
   - application of manure,
   - during the pasture period;
2. fertilizer use in agriculture;
3. industry, in especially fertilizer and ammonia production plants.

Other sources, of minor importance, are: human respiration, cats and dogs, sewage sludge, wild animals, traffic, natural soils and coal combustion.

The emission module distinguishes the following sources of ammonia emissions:

1. Livestock farming:
   - dairy cows,
   - other cattle (including buffaloes)
   - pigs,
   - laying hens,
   - broilers (including turkeys and ducks),
   - sheep (including goats, asses and mules)
   - horses.
2. Nitrogen fertilizer use
3. Industry (process emissions)
4. Other anthropogenic sources

Generally NH_3 emissions are calculated as a product of the emission coefficients and the level of activity (livestock population, fertilizer consumption and production, human population). The following description uses the indices i and l, to describe the nature of the parameters:

i	the type of animal
l	the country

Ammonia from livestock farming is released during three basic processes:

- in the stable and during storage of manure,
- during the application of manure,
- in the meadow or grazing period,

These processes are explicitly distinguished in the model since this enables the possibility to calculate the potential of emissions that can be reduced through abatement measures such as: direct application of manure into the soil, biofiltration of stable air and covering of manure storage facilities. The (unabated) ammonia emissions from livestock farming ($NH_3L_{i,l}$) are therefore calculated using the following equation:

$$NH_3L_{i,l} = (nh3s_{i,l} + nh3a_{i,l} + nh3m_{i,l}) * QL_{i,l} \qquad (1.1)$$

In which:

$nh3s_{i,l}$ emission coefficient of stable

$nh3a_{i,l}$ emission coefficient of application

$nh3m_{i,l}$ emission coefficient meadow

$QL_{i,l}$ animal population

This equation is used for each of the seven animal types.

Ammonia emissions resulting from the consumption of nitrogen fertilizer (NH_3F_l) depend on the amount of fertilizer used and the N-loss per fertilizer:

$$NH_3F_l = nf_l * 17/14 * QF_l \qquad (1.2)$$

In which:

nf_l the n-loss per fertilizer

QF_l the fertilizer consumption

Since the n-loss is expressed as per cent of the total nitrogen in the fertilizer the factor 17/14 is used to convert the losses expressed in nitrogen into ammonia. Note that fertilizer use and losses are country specific.

Industrial ammonia emissions are mainly related to the production of fertilizer and ammonia. The total industrial ammonia emissions (NH_3P_l) are therefore the product of the production of nitrogen fertilizer in each country and the emission coefficient:

$$NH_3P_l = nh3p * QP_l \qquad (1.3)$$

With:

$nh3p$ the emission coefficient for industry

QP_l N-fertilizer production

Other sources of ammonia are: human respiration, cats and dogs, sewage sludge, wild animals, traffic, natural soils and coal combustion. Of these sources human respiration is explicitly incorporated.

Remaining anthropogenic sources are included insofar as national data are available. However, emissions of natural soils and coal combustion are ignored in view of the large uncertainties in their order of magnitude (Buijsman et al, 1987). Buijsman et al. (1987) estimate total Europe wide ammonia emissions from natural soils at 750 kilotons of ammonia per year. This is some 10 per cent of the total ammonia emission in Europe. Other sources (NH_3O_l) are incorporated in the following manner:

$$NH_3O_l = nh3h * QH_l + Cnh3_l \qquad (1.4)$$

With:

nh3h	emission coefficient human population
QH_l	size human population
$Cnh3_l$	constant for other anthropogenic emissions

3. EMISSION COEFFICIENTS FOR LIVESTOCK ANIMALS

3..1. Introduction

In the past, several overviews have been made that describe ammonia emissions in Europe (Buijsman et al., 1987; Asman, 1989). A problem of the estimate made by Buijsman et al. (1987) is that they probably underestimate the emissions in view of more recent information (De Winkel, 1988; Möller and Schieferdecker, 1989). A weak spot of the emission calculation by Asman (1990) is that emission factors typically for one country, the Netherlands, although based on recent insights, are used to calculate emissions for every country. In view of large differences in agricultural practices, this seems inappropriate. Unfortunately, in contrast to the detailed information available about emission factors for NH_3 in the Netherlands, data on ammonia emission factors are available only for a few other European countries, for example Denmark (Sommer et al., 1984; Schröder, 1985; Laursen, 1989), Finland (Niskanen et al., 1990), the former German Democratic Republic (Möller and Schieferdecker, 1989), the Federal Republic of Germany (Isermann, 1990; Fabry et al., 1990), the Netherlands (Erisman, 1989), and the United Kingdom (ApSimon et al., 1989). For other countries, like Hungary, Czechoslovakia and Switzerland, estimates for NH_3 emissions are based on general rather than country specific emission factors (Bonis, 1981; Zavodsky and Mitosinkova, 1984; Stadelmann, 1988).

Therefore this study's starting point is the more recent information on emission coefficients in the Netherlands, summarized in Table 1. These emission coefficients are based on the work of a working group of scientists, established in the Netherlands to evaluate the present knowledge and to obtain more consistent and improved estimates on emission factors for NH_3 from livestock farming (De Winkel, 1988; Van der Hoek, 1989). For the most relevant animal categories the working group has derived average annual emission factors per animal. Emission factors for stall and storage, manure application and the meadow period were based on the application of nitrogen mass balances.

Their principle approach can be summarized in four equations:

N excretion = N feed - N retention (2.1)

N stable = N excretion * volatilization_s (2.2)

N application = (N excretion-N stable)*volatilization_a (2.3)

N meadow = N excretion * volatilization_m (2.4)

The results of nutritional research were used to compute the nitrogen content of the feed per animal (N feed) as well as the retention of nitrogen (N retention) in various animal products such as meat and milk. As a result the nitrogen remaining in the excretion (N excretion) could be calculated. The volatilization of ammonia in the stall and during storage of manure (volatilization_s), or in other words the loss of nitrogen, was determined by looking at the difference between the N/P ratio in excrements and in stored manure. P is regarded as a conservative component, whereas N may evaporate as NH_3. The volatilization of ammonia can then be computed from changes in the N/P ratio during storage. The volatilization coefficient of ammonia (volatilization_a) during application (N application) and during the grazing or meadow period (volatilization_m) was based on experiments described in the literature and additional experiments carried out by various research groups. Were possible the average emissions factors per animal were differentiated for different housing systems using recent emission measurements. The more detailed results for the Netherlands are included in Appendix I. These results have been summarized per animal category (dairy cows, other cattle, pigs, laying hens, broilers, sheep and horses) using data for 1988 on the composition of the animal population in the Netherlands (Central Bureau of Statistics, 1989). One should note that in view of recent information (Van der Hoek, 1989; Voermans, 1989) the emission coefficients in Table 1 might be overestimated for poultry and underestimated for pigs.

In the remaining sections it will be explained how the emission coefficients of Table 1 were modified for several livestock categories to arrive at country specific emission coefficients.

3..2. Emission coefficients for dairy cows

Regarding dairy cows, the major elements influencing emission factors are:

- feed composition, amount and its nitrogen content,
- retention of nitrogen in milk and meat,
- volatilization of ammonia in the stable,
- volatilization of ammonia during application,
- volatilization of ammonia in the meadow period.

Van Dijk and Hoogervorst (1984) indicate that the share of grass in the total feed consumption differs among countries. Moreover, the nitrogen content of the grass will differ since the amounts of nitrogen fertilizer applied on a pasture varies between countries (CEC, 1989). In addition, international statistics show that large differences in the annual milk production per cow exist. This suggests that the retention of nitrogen in milk might differ considerably amongst countries. As a result, the nitrogen content of the excretion is likely to vary between countries. The volume of ammonia emitted in the stall and during storage depends on the volatilization coefficient and the stall period. The number of days spent in the stall varies (Asman, 1990). In Austria, for example, the meadow period is 109 days whereas in The Netherlands it is 175 days. Method of storing manure, stable type and type of manure (liquid/solid) are other factors affecting ammonia volatilization in the stall. Although differences amongst countries do exist, lack of data (Asman, 1990) does not allow to quantify the impact of these other factors on the volatilization. Emission during application depends on factors such as the type of manure (liquid/solid), soil type, temperature, wind speed and method of applying manure (Iserman, 1990). In summary, on one hand it does not seem appropriate to use the emission coefficients from the Netherlands for other countries. However on the other hand, for only a few of the potentially large number of factors affecting emissions, data is available.

To compute country specific emission coefficients for dairy cows in RAINS we decided to take into account differences in the level of nitrogen fertilizer application as well as differences in meadow and stall period. For both these elements data was available on a country by country basis. Moreover, the differences in meadow periods were thought to be relevant because they influenced the volume of NH_3 emission released during stall, application and meadow period. Consequently, this affects the potential of emissions to be abated and the related abatement costs, which is the subject of another part of the RAINS model (Klaassen, 1990).

The method that has been used is the following. A recent study (Baltussen et al, 1990) indicates that there is a relationship between the nitrogen excretion of dairy cows and the nitrogen level of grassland. The nitrogen level of grassland is, to a large extent, determined by the amount of fertilizer applied. Based on data for the Netherlands the following relation has been estimated:

$$\text{N-excretion} = 126.22252 + 0.1932 * \text{N-fertilizer} \qquad (2.1)$$

In which N-excretion is the nitrogen excretion per animal and N-fertilizer is the fertilizer use per hectare. This relation has been used to estimate the N-excretion for other countries in Europe. The relation between the N-excretion per dairy cow in the Netherlands and the other countries is then used to correct the Netherlands emission factors. Details on the method and the data used are provided in Appendix II. In addition, the amount of N-excretion produced in the meadow period and the stall period has been corrected using information on the meadow periods in several countries in Europe (Asman, 1990). This is based on the following equations:

$$\text{N-excretion stall} = \text{N\_excretion} * \text{st period/st period NL} \qquad (2.2)$$

$$\text{N-excretion meadow} = \text{N\_excretion} * \text{meadowperiod/meadow NL} \qquad (2.3)$$

where st period is the stall period in the specific country (in days) and st period NL is the stall period in the Netherlands (in days/year). Using equations (2.1) to (2.3) and data on the volatization factors based on De Winkel (1988), country specific emission coefficients for stall, application and meadow have been calculated for dairy cows. Details are provided in Appendix II.

The resulting emission coefficients are presented in Table 2. Total emission coefficients vary between 24.0 kg NH_3/animal per year and 35.5 kg NH_3/animal per year, mainly due to the differences in fertilizer level. The coefficients for stall, application and meadow differ roughly by a factor two. These differences considerably influence the potential for abatement in the various countries. It is recalled however, that we were not able to take into account all the relevant factors. For example, ammonia emission in Southern European countries might be underestimated since manure is usually stored outside as solid manure. Although the nitrogen content of the excretion might be less, this method of storing manure is likely to increase the ammonia emission again.

3..3. Other cattle

For other cattle there also may be differences among countries regarding the nitrogen content of the feed, nitrogen retention in meat, and the volatilization during stall and storage and the application of manure. Due to a lack of data, we were only able to take into the composition of the category other cattle (in young cattle, fattening calves etc.) to calculate country specific coefficients on the basis of the emission coefficients for the Netherlands (see Appendix I). The results are presented in Table 3.

3..4. Pigs, laying hens, broilers and horses

For these animals nitrogen content of the excretion may differ among countries due to differences in nitrogen content of the feed and nitrogen retention. In addition, the ammonia emitted from stall and manure might vary due to differences in stall type (mechanical/natural ventilation for example; Asman, 1990) and manure storage system. Differences in stable and manure handling systems are likely to cause differences in ammonia emissions from the stall (Voermans, 1989) especially for laying hens. However, the stall period will not differ too much since pigs and poultry are usually inside the whole year (Asman, 1990). The losses of ammonia during application may also differ in view of differences in the usual factors affecting ammonia volatilization during application such as temperature, soil type, manure type and method of handling the manure. Due to lack of data we used the data from the Netherlands (Table 1) for each country for pigs, laying hens, broilers and horses.

3..5. Sheep

For sheep differences in meadow period and the composition of the sheep flock over sheep and goats have been taken into account to arrive at country specific factors. The Netherlands emission factors (Table 1) were modified as follows. Ammonia losses (as kg NH_3 per animal per year) in the stall (N_stall), during application (N_application), and in the meadow (N_meadow) are calculated as follows.

$$N\_stall = N\_excretion * stall\ period * 0.12 * 17/14 \quad (3.1)$$

$$N\_application = N\_excretion * (1 - 0.12) * stall\ period * 0.25 * 17/14 \quad (3.2)$$

$$N\_meadow = N\_excretion * meadow\ period * 0.12 * 17/14 \quad (3.3)$$

where N_excretion is the nitrogen content in the excretion per animal per year in the Netherlands. The stall period is expressed as part of the year. 0.12 is the part of the nitrogen in the excretion that is released as ammonia in the stall (Equation 3.2) as well as in the meadow (Equation 3.3). During application, a share of 0.25 is released of the nitrogen in excretion, taking into account the loss that already occurred in the stable (1 - 0.12). The N_excretion used is 9.8535 kg N/animal per year for sheep (including lambs) and 15.567 kg for goats. All data is based on van de Hoek (1989) using the above equations, data on the meadow period (derived from Asman, 1990: see Appendix III for details), and the number of sheep and goats in each country (FAO, 1989a), the average emission coefficients for the category sheep in each country have been calculated (Table 4).

Table 4 shows that emission coefficients vary between 1.3 kg NH_3 per animal per year (United Kingdom) and 3.3 kg NH_3 per animal per year (Finland) as a result of differences in meadow period and the ratio between sheep and goats. One should realize, however, that the data on nitrogen excretion and volatilization factors were still based on Dutch data.

3..6. A comparison with other emission coefficients

Table 7 compares the results of the emission coefficients used in RAINS with the ones of Buijsman et al. (1987), Möller and Schieferdecker (1989) and The Netherlands. The RAINS emission coefficients for dairy cows are well within the coefficients used by Buijsman and Möller but the recent Dutch ones (Table 1) are generally higher. Note that Buijsman does not explicitly distinguish between dairy cows and other cattle. The emission coefficients for other cattle are somewhat lower in RAINS than in the other sources. The average, country specific emission coefficients in RAINS for cattle (dairy cows and other cattle) lie well between the averages used by Buijsman et al. (1987) and Möller and Schieferdecker (1989). For pigs RAINS estimates, based on De Winkel (1988), are in between the ones of Buijsman (1987) and Möller (1989). The emission coefficients for poultry (laying hens and broilers) are comparable although Buijsman et al. and Möller and Schieferdecker only provide coefficients for the total poultry. Estimates in RAINS for sheep are below both other sources. Emissions coefficients for horses are in between both other estimates. Major differences thus appear to exist for cattle (i.e. dairy cows), pigs and sheep.

4. FERTILIZER USE

Ammonia emissions released when nitrogen fertilizer is applied depend on elements such as: the type of fertilizer, soil PH and cation exchange capacity, drying conditions and irrigation. In this study we use the average emission coefficient for each type of fertilizer used by Buijsman et al. (1987) and Asman (1990). Using information on the type of fertilizer for each country (Buijsman et al. 1985; FAO, 1989), average N-losses as ammonia from fertilizer have be determined (Table 5). The emission factors that have been used per type of fertilizer are presented in Table 6. Appendix IV gives details on the composition of the fertilizer use in each country used to determine these average emission factors.

5. INDUSTRY AND OTHER ANTHROPOGENIC SOURCES

Ammonia production and fertilizer plants are the main sources of industrial ammonia emissions. Following Buijsman et al. (1987) we assume the total production of fertilizer in each country to be proportional to the ammonia production. Emission coefficients for ammonia plants are taken as 0.8 kg NH_3 /ton fertilizer produced (Ministry of Housing, Physical Planning and Environment, 1983). According to the same source emission factors for fertilizer plants may vary between 0.01 kg NH_3 per ton and 12.5 kg NH_3 per ton produced. As Buijsman et al. (1987) we assume an average coefficient of 5 kg NH_3/ ton fertilizer produced. As a result, the total emission coefficient we used for industrial ammonia sources is 5.8 kg NH_3/ton fertilizer produced.

For human population we use an emission coefficient of 0.3 kg NH_3/head (Buijsman, 1984; Erisman, 1989). For the other anthropogenic sources, different national sources have been used to estimate these (Stadelman, 1988; Möller and Schieferdecker, 1989; Erisman, 1989; Niskanen et al. 1990). Table 9 (second column) provides the findings. In all cases natural sources such as soils have been excluded.

6. RESULTS AND DISCUSSION

The ammonia emissions for 1980 and 1987 have been calculated using the emission coefficients (Table 1 to 6) and data on livestock population, fertilizer consumption and production, as well as human population. The data used on livestock population are based on FAO (1982b, 1988, 1989b) and national livestock statistics for Belgium and Luxembourg (Table 8 and 9). The data on the USSR refer only to that part of the USSR that is within the grid used by EMEP (European Monitoring and Evaluation Program). That includes the USSR republics Ukraine, White Russia, Georgia, Azerbajdzjan, Lithunia and Moldavia. These data are based on Buijsman et al. (1987) and Asman (1990). Data on fertilizer use (Table 10) is based on FAO (1982a, 1989a). For the USSR, however data from Buijsman et al. (1989) and the British Sulphur Corporation (1987) were used. Human population data (Table 11) are based on FAO (1982b), United Nations (1989a, 1989b) and estimates of IIASA's Population Programm for the EMEP part of the USSR.

Table 12 presents the results for 1980. Total ammonia emissions amount to 7045 kton. The major sources of ammonia emissions are dairy cows, other cattle, pigs and fertilizer use. Countries with a major contribution to the emissions are France, FRG, Poland and the USSR. Table 13 shows that ammonia emissions rose only slightly from 1980 to 1987. Decreases in the emissions from dairy cows were compensated by increases in emissions from pigs, poultry (laying hens and broilers) and fertilizer use. The country-by-country picture shows large differences: emissions in Turkey and Poland, for example, decreased considerably, emissions in Rumania and the Netherlands increased from 1980 to 1987 whereas emissions in a large number of countries stabilized (e.g. Austria, Belgium, France, Italy).

Table 14 compares our estimates for the major sources of ammonia with previous ones. The table indicates that our estimates for 1980 are about 10 per cent higher than the ones from Buijsman et al.(1987) for the early eighties. This is mainly due to the fact that our estimates for pigs and poultry are higher and we include estimates for other sources. By contrast our estimates for sheep are lower. Estimates for cattle, fertilizer use and industry have the same order of magnitude. Note that part of the differences are caused by the fact that not only emission coefficients but also data on animal population and fertilizer use are somewhat different. Table 14 also shows that our overall estimate for 1987 is 15 per cent lower than the one by Asman (1990). The main reason is that our estimates for cattle and for fertilizer use are lower. For cattle this is so because we use country specific emission factors for dairy cows which are generally lower than Asman. For fertilizer use our estimates are lower chiefly because we take into account the difference in nitrogen loss between calcium ammonium nitrate and ammonium nitrate (compare Buijsman et al., 1985). Estimates for industry are higher since we include both fertilizer and ammonia production, as well as the EMEP part of the USSR as sources. Figures for pigs, poultry, sheep are comparable.

Table 15 compares the emissions of various authors on a country-by-country basis. The Table indicates that IIASA estimates for 1980 are considerably higher for some countries (the Netherlands, FRG) than the Buijsman et al. (1987) computation. For several countries (Turkey e.g.) the IIASA estimate is lower. Generally IIASA estimates for 1987 are lower than the ones by Asman (1990), (for example, Spain, France and the FRG) but are sometimes higher (for example Norway), since IIASA includes other sources as well. Estimates for countries thus show considerably larger differences (up to 40 per cent) than the ones for Europe as a whole.

The fact that country estimates differ considerably can also be concluded when comparing Table 16 (National estimates) with Table 15. IIASA estimates differ with 10 to 20 per cent with national estimates. In view of the lack of fundamental data (nitrogen content feed, volatilization factors) for most countries the calculation of country specific ammonia emission coefficients using nitrogen mass balance, as was done in the Netherlands, is difficult. This also implies that it will be difficult to reduce the uncertainty in the emission estimates. Realizing this uncertainty, a comparison of Table 15 with Table 16 indicates that RAINS estimates correspond fairly well with national estimates.

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Table 1 Emission coefficients for livestock animals in The Netherlands (Per animal in KG NH_3/Annum.)

Subcategory	Emission coefficient			
	Stall/ Storage	Application	Meadow period	TOTAL
DAIRY AND CALF COWS	8.79	14.40	12.34	35.52
OTHER CATTLE	3.61	6.14	2.74	12.49
PIGS	1.87	2.96	0.00	4.82
LAYING HENS	0.15	0.17	0.00	0.33
BROILERS	0.21	0.08	0.00	0.28
SHEEP 1)	0.39	0.71	0.96	2.06
HORSES 2)	5.00	4.00	3.50	12.50

Data based on de Winkel (1988).
1) Van der Hoek (1989).
2) Asman (1990)
3) New data (van der Hoek, 1989; Voermans, 1989) suggest that emission factors for stables are higher for pigs and lower for poultry.
4) Other cattle include buffaloes. Sheep include goats. Broilers include turkeys and ducks.

Table 2 Dairy cows emission coefficients (KG NH_3 per animal per year).

COUNTRY	PROCESS stall/ storage	application	meadow	total
Albania	6.6	10.7	10.0	27.3
Austria	8.5	13.9	5.6	27.9
Belgium	4.5	7.5	15.1	27.1
Bulgaria	6.6	10.8	10.0	27.3
Czechoslovakia	5.7	9.4	14.8	29.9
Denmark	10.3	16.9	8.1	35.3
Finland	9.3	15.2	7.3	31.8
France	6.7	10.9	10.2	27.8
FRG	11.7	19.1	4.4	35.2
GDR	7.3	11.9	11.1	30.3
Greece	6.2	10.1	9.4	25.6
Hungary	6.9	11.2	10.7	28.8
Ireland	6.2	10.1	9.4	25.8
Italy	6.4	10.5	9.8	26.8
Luxembourg	7.1	11.7	11.2	29.9
Netherlands	8.8	14.4	12.3	35.5
Norway	4.9	8.0	15.2	28.0
Poland	6.7	11.0	10.2	27.9
Portugal	6.3	10.4	9.6	26.3
Romania	6.6	10.8	10.0	27.4
Spain	6.1	10.0	9.3	25.4
Sweden	4.9	8.1	12.8	25.7
Switzerland	6.0	9.8	9.1	24.9
Turkey	5.0	8.2	10.9	24.0
UK	6.5	10.6	10.2	27.3
USSR	5.9	9.6	8.9	24.4
Yugoslavia	6.1	9.9	9.3	25.3

Table 3 Emission Coefficients other cattle (In KG NH_3 per animal per year).

COUNTRY	PROCESS Stall/ Storage	Application	Meadow	TOTAL
Albania	3.6	6.1	2.7	12.5
Austria	3.5	5.9	3.4	12.8
Belgium	3.3	5.5	5.1	13.9
Bulgaria	3.6	6.1	2.7	12.5
CSSR	3.6	6.1	2.7	12.5
Denmark	3.0	5.3	3.1	11.4
Finland	2.1	3.9	3.8	9.8
France	3.6	6.1	2.7	12.5
FRG	3.6	6.2	2.5	12.3
GDR	3.6	6.1	2.7	12.5
Greece	3.6	6.1	2.7	12.5
Hungary	3.6	6.1	2.7	12.5
Ireland	3.6	6.1	2.7	12.5
Italy	3.6	6.1	2.7	12.5
Luxembourg	3.4	5.6	5.4	14.4
Netherlands	3.6	6.1	2.7	12.5
Norway	3.6	6.1	2.7	12.5
Poland	3.6	6.1	2.7	12.5
Portugal	3.6	6.1	2.7	12.5
Romania	3.6	6.1	2.7	12.5
Spain	3.6	6.1	2.7	12.5
Sweden	2.9	5.2	2.2	10.3
Switzerland	3.6	6.1	2.7	12.5
Turkey	3.6	6.1	2.7	12.5
UK	3.1	5.2	4.3	12.6
USSR	3.6	6.1	2.7	12.5
Yugoslavia	3.6	6.1	2.7	12.5

Table 4 Emission Coefficients sheep and goat (in KG NH_3 per animal per year).

COUNTRY	PROCESS stall/ storage	appli- cation	meadow	total
Albania	0.4	0.8	1.3	2.5
Austria	0.0	0.0	1.9	1.9
Belgium	0.0	0.0	1.7	1.7
Bulgaria	0.3	0.6	1.0	2.0
Czechoslovakia	0.3	0.6	1.0	2.0
Denmark	0.3	0.6	1.0	1.9
Finland	0.9	1.6	0.4	3.0
France	0.3	0.6	1.0	2.0
FRG	0.6	1.0	0.8	2.4
GDR	0.3	0.6	1.0	1.9
Greece	0.4	0.7	1.2	2.2
Hungary	0.3	0.6	1.0	1.9
Ireland	0.3	0.6	1.0	1.9
Italy	0.3	0.6	1.0	2.0
Luxembourg	0.4	0.8	1.3	2.5
Netherlands	0.4	0.7	0.9	2.0
Norway	0.9	1.6	0.5	2.9
Poland	0.3	0.6	1.0	1.9
Portugal	0.4	0.7	1.1	2.1
Romania	0.3	0.6	1.0	2.0
Spain	0.4	0.7	1.1	2.1
Sweden	0.9	1.6	0.4	2.9
Switzerland	0.4	0.7	1.1	2.1
Turkey	0.4	0.7	1.2	2.2
UK	0.0	0.0	1.3	1.3
USSR	0.3	0.6	1.0	2.0
Yugoslavia	0.3	0.6	1.0	1.9

Table 5 Average N-Losses of fertilizers (% Loss of N-Content).

COUNTRY	
Albania	6.0
Austria	3.4
Belgium	3.4
Bulgaria	5.0
Czechoslovakia	5.0
Denmark	4.6
Finland	4.8
France	4.4
FRG	4.2
GDR	8.0
Greece	7.5
Hungary	7.6
Ireland	5.2
Italy	7.2
Luxembourg	3.4
Netherlands	2.7
Norway	5.1
Poland	9.9
Portugal	5.4
Romania	5.0
Spain	6.3
Sweden	4.9
Switzerland	4.8
Turkey	7.4
UK	7.4
USSR	5.0
Yugoslavia	5.0

Table 6 Emission factors for N-Fertilizer (% Loss of N-Content).

ammonium	sulphate		15
ammonium	nitrate		10
ammonium	sulphate	nitrate	12.5
calcium	ammonium	nitrate	2
urea			10
ammonium	phosphate		5
other	nitrogen	fert.	5
other	complex	fert.	5
other	not	specified	5

Table 7 Comparison of emission coefficients (In KG NH_3 per animal per year).

LIVESTOCK CATEGORY	REFERENCE RAINS (1990)	Buijsman (1987)	Moeller (1989)	The Netherlands (1988/1989)
DAIRY COWS	24.0-35.5	18.4	42.5	35.5
OTHER CATTLE	9.8-14.4	18.4	18.7	12.5
PIGS	4.8	2.8	6.3	4.8
LAYING HENS	0.33	0.26	0.27	0.33
BROILERS	0.28	0.26	0.27	0.28
SHEEP	1.3-3.0	3.1	3.6	2.1
HORSES	12.5	9.4	18.2	12.5

Table 8 Livestock population 1980 (1000 Heads)

SECTOR COUNTRY	DAIRY COWS	OTHER CATTLE &	PIGS	LAYING HENS	BROILERS *	SHEEP #	HORSES
Albania	155	324	125	1400	2600	1892	43
Austria	975	1573	4004	4468	10318	230	43
Belgium	975	1932	4999	11448	17147	116	37
Bulgaria	686	1153	3830	17436	23561	11306	120
Czechoslovakia	1855	3060	7588	22532	25819	938	47
Denmark	1054	1907	9957	4897	11703	56	58
Finland	709	1044	1451	6041	3370	108	33
France	9985	13934	11446	72600	127942	13060	364
FRG	5469	9581	22374	45275	42586	1181	66
GDR	2121	3475	12132	26500	24944	2004	120
Greece	385	547	948	15700	14048	12756	380
Hungary	685	245	8355	31487	34663	2987	126
Ireland	1587	5348	1120	2800	6616	3355	78
Italy	3781	5027	8807	42410	86890	10221	273
Luxembourg	68	136	68	52	78	5	2
Netherlands	2356	2672	10138	37454	45255	888	67
Norway	375	601	650	2824	755	2115	19
Poland	5860	6789	21326	74123	10778	4237	1780
Portugal	309	801	3300	5200	12100	6138	29
Romania	2116	4397	10899	41077	54340	16231	566
Spain	1852	2643	10715	52294	1	16345	242
Sweden	656	1279	2714	5937	7540	399	57
Switzerland	875	1156	2205	3170	3018	436	45
Turkey	5931	10688	13	24300	41114	66132	807
UK	3296	10130	7815	57928	66114	31457	140
USSR	15535	25952	30953	125850	223146	20958	1556
Yugoslavia	2761	2675	7502	18815	47204	7504	617
EUROPE	72412	119069	205434	754018	943650	233055	7715
USSR-tot	43310	72350	79501	579840	594160	148701	5900

Source: FAO (1982b), FAO (1988). USSR-emep part based on Asman(1990
Probst (1982) for laying hens in several countries.
#: including goats, asses and mules.
&: including buffalos
*: includes chickens, ducks and turkeys.

Table 9 Livestock population 1987 (1000 Heads)

SECTOR / COUNTRY	DAIRY COWS	OTHER CATTLE &	PIGS	LAYING HENS	BROILERS *	SHEEP #	HORSES
Albania	245	407	212	1923	3077	2444	42
Austria	976	1661	3801	4701	9299	278	44
Belgium	920	1852	5686	10181	21674	177	22
Bulgaria	625	1079	4050	16809	22191	10371	121
Czechoslovakia	1794	3279	6833	19698	29302	1191	46
Denmark	811	1512	9048	4237	11763	77	29
Finland	580	905	1309	6244	756	69	39
France	9493	13310	12419	70225	147775	11670	300
FRG	5074	10231	24503	41549	34451	1428	368
GDR	2022	3782	12840	24823	25177	2680	105
Greece	350	456	1191	17387	13613	14928	65
Hungary	577	1148	8677	17151	48849	2358	95
Ireland	1490	4136	980	3260	5130	3703	55
Italy	3021	5798	9278	48543	85457	12795	253
Luxembourg	64	131	77	46	99	8	2
Netherlands	2035	2860	14349	35090	62910	1019	64
Norway	348	597	779	3564	436	2340	17
Poland	4925	5598	18546	51685	6315	4749	1141
Portugal	388	935	2920	6171	11829	6160	29
Romania	2110	5115	14711	50511	86489	19702	686
Spain	1793	3210	15782	53276	724	20745	249
Sweden	576	1080	2234	6036	4964	397	57
Switzerland	788	1070	1917	2997	3003	438	48
Turkey	5200	7490	10	32224	28776	54610	620
UK	3242	9234	7955	55494	74506	26034	175
USSR	15209	28591	33300	135887	281813	20800	1639
Yugoslavia	2582	2475	8459	19758	54242	7974	384
EUROPE	67238	117942	221866	926905	949795	228922	6695

Source: FAO (1989a, 1988). USSR-EMEP based on Asman (1990).
Data on laying hens for some countries derived from Probst (1982).
#: including goats, asses and mules.
&: including buffaloes
*: includes chickens, ducks and turkeys.

Table 10 Fertilizer use (Ton/Year)

COUNTRY	N-FERTILIZER CONSUMPTION 1980	N-FERTILIZER CONSUMPTION 1987	N-FERTILIZER PRODUCTION 1980	N-FERTILIZER PRODUCTION 1987
Albania	66350	75000	70000	75000
Austria	158850	136700	287500	194000
Belgium	179868	187300	749550	795000
Bulgaria	435276	440000	703555	817929
Czechoslovakia	652500	646200	692850	700000
Denmark	384000	381263	134219	175985
Finland	196589	217965	270135	294000
France	2140650	2568400	1710000	1530000
FRG	1514152	1578342	1456203	1019231
GDR	749700	708900	909007	1252100
Greece	344700	432143	315650	355925
Hungary	553457	593393	645372	672216
Ireland	261300	343000	146100	255400
Italy	1059445	1010607	1455692	1144859
Luxembourg	15861	16516	0	0
Netherlands	484467	503959	1618010	1742413
Norway	107850	109700	440050	384100
Poland	1306245	1388115	1332786	1445231
Portugal	145772	149800	192945	166000
Romania	716150	1062500	1722500	1900000
Spain	905026	1105150	957221	987800
Sweden	250074	240866	175752	160274
Switzerland	65050	71100	33950	36200
Turkey	700500	1056080	408200	692448
UK	1277000	1671000	1241500	1318000
USSR	761574	1452166	5768700	6978600
Yugoslavia	428500	506000	404950	523000
EUROPE	15860903	17787881	18073694	18637111

Table 11 Human population (1000 Heads) and NH_3 emission of other sources.

COUNTRY	HUMAN POPULATION (IN 1000 HEADS) 1980	1987	NH3 EMISSION OTHER SOURCES (KTON NH3)
Albania	2732	3083	0
Austria	7505	7573	0
Belgium	9852	9919	0
Bulgaria	8862	8970	0
Czechoslovakia	15281	15558	0
Denmark	5126	5127	0
Finland	4778	4933	4
France	53686	55632	0
FRG	61561	61171	0
GDR	16737	16641	0
Greece	9600	9993	0
Hungary	10710	10613	0
Ireland	3308	3543	0
Italy	57042	57331	0
Luxembourg	364	368	0
Netherlands	14144	14661	7
Norway	4086	37664	0
Poland	35578	37664	0
Portugal	9836	10350	0
Romania	22201	22936	0
Spain	37199	38832	0
Sweden	8316	8399	0
Switzerland	6366	6538	3
Turkey	45254	51350	0
UK	56710	56917	0
USSR	162644	173399	0
Yugoslavia	22340	23411	0
EUROPE	691818	18637111	14

Table 12 NH_3 Emission in 1980 (In kilotons NH_3).

SECTOR / COUNTRY	DAIRY COWS	OTHER CATTLE &	PIGS	LAYING HENS	BROILERS *	SHEEP /	HORSES	FERTI-LIZER	INDUS-TRY	OTHER SOURCES	TOTAL
Albania	4	4	1	0	1	5	1	5	0	1	21
Austria	27	20	19	1	3	0	1	6	2	2	82
Belgium	26	27	24	4	5	0	0	7	4	3	101
Bulgaria	19	14	18	6	7	22	2	26	4	3	121
Czechoslovakia	55	38	37	7	7	2	1	40	4	5	196
Denmark	37	22	48	2	3	0	1	22	1	2	137
Finland	23	10	7	2	1	0	0	11	2	6	62
France	277	174	55	24	36	27	5	115	10	16	739
FRG	192	118	108	15	12	3	1	78	8	18	553
GDR	64	43	59	9	7	4	2	73	5	5	270
Greece	10	7	5	5	4	29	5	32	2	3	100
Hungary	20	3	40	10	10	6	2	51	4	3	149
Ireland	41	67	5	1	2	6	1	17	1	1	142
Italy	101	63	42	14	25	21	3	92	8	17	387
Luxembourg	2	2	0	0	0	0	0	1	0	0	5
Netherlands	84	33	49	12	13	2	1	16	9	11	230
Norway	11	8	3	1	0	6	0	7	3	1	39
Poland	163	85	103	24	3	8	22	157	8	11	584
Portugal	8	10	16	2	3	13	0	10	1	3	66
Romania	58	55	53	13	15	32	7	43	10	7	294
Spain	47	33	52	17	0	34	3	69	6	11	272
Sweden	17	13	13	2	2	1	1	15	1	2	68
Switzerland	22	14	11	1	1	1	1	4	0	5	59
Turkey	142	133	0	8	12	148	10	63	2	14	533
UK	90	128	38	19	19	41	2	114	7	17	475
USSR	378	324	149	41	64	41	19	46	33	49	1146
Yugoslavia	70	33	36	6	13	14	8	26	2	7	216
EUROPE	1989	1482	991	246	269	467	96	1145	138	221	7045

Table 13 NH_3 Emission in 1987 (In Kilotons NH_3)

SECTOR COUNTRY	DAIRY COWS	OTHER CATTLE	PIGS	LAYING HENS	BROILERS	SHEEP	HORSES	FERTI-LIZER	INDUS-TRY	OTHER SOURCES	TOTAL
Albania	7	5	1	1	1	6	1	5	0	1	28
Austria	27	21	18	2	3	1	1	6	1	2	81
Belgium	25	26	27	3	6	0	0	8	5	3	103
Bulgaria	17	13	20	5	6	20	2	27	5	3	118
Czechoslovakia	54	41	33	6	8	2	1	39	4	5	193
Denmark	29	17	44	1	3	0	0	22	1	2	119
Finland	18	9	6	2	0	0	0	13	2	5	56
France	264	166	60	23	42	24	4	138	9	17	746
FRG	178	126	118	14	10	3	5	81	6	18	559
GDR	61	47	62	8	7	5	1	69	7	5	273
Greece	9	6	6	6	4	33	1	40	2	3	109
Hungary	17	14	42	6	14	5	1	55	4	3	160
Ireland	38	52	5	1	1	7	1	22	1	1	129
Italy	81	72	45	16	24	26	3	88	7	17	379
Luxembourg	2	2	0	0	0	0	0	1	0	0	5
Netherlands	72	36	69	11	18	2	1	16	10	11	247
Norway	10	7	4	1	0	7	0	7	2	11	50
Poland	137	70	89	17	2	9	14	167	8	11	525
Portugal	10	12	14	2	3	13	0	10	1	3	68
Romania	58	64	71	16	25	39	9	65	11	7	364
Spain	46	40	76	17	0	43	3	84	6	12	328
Sweden	15	11	11	2	1	1	1	14	1	3	60
Switzerland	20	13	9	1	1	1	1	4	0	5	55
Turkey	125	94	0	11	8	123	8	95	4	15	481
UK	89	117	38	18	21	34	2	149	8	17	493
USSR	370	357	161	44	80	41	20	88	40	52	1255
Yugoslavia	65	31	41	6	15	15	5	31	3	7	220
EUROPE	1843	1469	1070	241	306	461	84	1342	149	240	7205

Source: Own calculations based on Asman (1989), FAO (1989a, 1989b) and van der Hoek (1989).

Table 14 NH_3emission according to source and estimate (KTON NH_3).

ESTIMATE / SOURCE	Buijsman et al. (1987) early 80	IIASA 1980	IIASA 1987	Asman (1990) 1987
Cattle	3517	3471	3312	4660
Pigs	516	991	1070	1059
Poultry	425	515	547	570
Sheep	705	467	461	435
Horses	78	96	84	84
Fertilizer	1091	1145	1342	1626
Industry	102	138	149	13
Other	0	221	240	0
Total	6434	7045	7205	8447

Table 15 NH_3 emission per country and estimates (KTON NH_3).

ESTIMATE COUNTRY	Buijsman et al. (1987) 1980/83	IIASA 1980	IIASA 1987	Asman (1990) 1987
Albania	21	21	28	32
Austria	72	82	81	107
Belgium	82	101	103	123
Bulgaria	126	121	118	123
Czechoslovakia	170	196	193	219
Denmark	111	137	119	144
Finland	44	62	56	61
France	709	739	746	974
FRG	371	553	559	718
GDR	207	270	273	274
Greece	95	100	109	111
Hungary	130	149	160	179
Ireland	117	142	129	188
Italy	361	387	379	435
Luxembourg	5	5	5	7
Netherlands	150	230	247	276
Norway	36	39	50	38
Poland	405	584	525	561
Portugal	47	66	68	76
Romania	301	294	364	387
Spain	232	272	328	365
Sweden	52	68	60	74
Switzerland	53	59	55	68
Turkey	683	533	481	573
UK	405	475	493	548
USSR	1256	1146	1255	1543
Yugoslavia	198	216	220	235
EUROPE	6434	7045	7205	8447

Table 16 National NH_3 estimates (KTON NH_3).

ESTIMATE COUNTRY	NH3 EMISSION (KTON NH3)	YEAR	REFERENCE
CSSR	128-222 3)	1981	Zavodsky et al. (1984)
Denmark	106-138 2)	78/82	Sommer et al (1984)
	196 1)	85/86	Schroeder (1985)
	155 1)	1980	Laursen (1989)
Finland	52	84/86	Niskanen et al. (1990)
FRG	348-360	1988	Fabry et al. (1990)
	641 1)	1986	Isermann (1990)
GDR	345-355 3)	80/85	Moeller et al.(1989)
Hungary	90-157	1976	Bonis (1981)
	150	80/87	Fekete (1990)
Netherlands	258	1987	Erisman (1989)
Norway	57 1)	80/89	Bockmann et al. (1990)
Switzerland	63 3)	1987	Stadelman (1988)
UK	451 1)	83/84	Apsimon et al. (1989)

1) Only agricultural sources.
2) Livestock manure only.
3) Includes emissions from natural sources

APPENDIX I. DETAILED EMISSION COEFFICIENTS

IN THE NETHERLANDS (PER AVERAGE PRESENT ANIMAL IN KG NH3/ANNUM)

CBS no.	Subcategory	Emission factor			
		Stable/ Storage	Spreading	Grazing period	TOTAL
211 1)	DIARY AND CALF COWS	8.789	14.398	12.336	35.523
201-209	young cattle	3.869	6.339	4.253	14.461
213	breeding bulls > 2 yr	10.579	17.391	0.000	27.970
215	fattening calves	1.602	3.631	0.000	5.233
217-227	young cattle for fattening	5.759	9.435	0.000	15.194
229	fattening/grazing cattle > 2 yr	0.000	0.000	12.336	12.336
Subtotal	OTHER CATTLE	3.609	6.140	2.741	12.489
235-237	piglets < 20 kg (included in 239)	0.000	0.000	0.000	0.000
239-241	fattening pigs	2.029	4.117	0.000	6.146
243	breeding pigs 20-50 kg	1.219	3.099	0.000	4.318
245	breeding sows > 50 kg	4.156	4.639	0.000	8.795
247-251	other sows	8.094	8.036	0.000	16.130
253	boars > 50 kg	2.029	4.117	0.000	6.146
255	mature boars	5.517	5.478	0.000	10.995
Subtotal	PIGS	1.869	2.955	0.000	4.824
265	lambs (included in 266)	0.000	0.000	0.000	0.000
266	ewes	0.700	1.280	2.090	4.070
268	rams (included in 266)	0.000	0.000	0.000	0.000
282	milch goats	2.300	4.100	0.000	6.400
284	other goats (included in 268)	0.000	0.000	0.000	0.000
Subtotal	SHEEP	0.389	0.709	0.961	2.058
275	laying hens < 18 weeks	0.088	0.117	0.000	0.205
276-277	laying hens > 18 weeks	0.175	0.190	0.000	0.365
Subtotal	LAYING HENS	0.154	0.172	0.000	0.326
269	slaughter chickens	0.208	0.072	0.000	0.280
271	mother animals < 5 months	0.142	0.128	0.000	0.270
273	mother animals > 5 months	0.314	0.283	0.000	0.597
287	ducks	0.117	0.000	0.000	0.117
291	turkeys for slaughter	0.429	0.429	0.000	0.858
293	turkeys < 7 months	0.445	0.445	0.000	0.890
295	turkeys > 7 months	0.639	0.639	0.000	1.278
Subtotal	OTHER POULTRY	0.209	0.076	0.000	0.285
260-263	HORSES (includes ponies)	5.000	4.000	3.500	12.500

CBS refers to the Netherlands Central Bureau of Statistics division
Data based on de Winkel (1988).
1): difference in grazing system reflected. If not
incorporated this leads to the following factors:
12.877 (stable), 21.161 (spreading), 8.638 (grazing).

APPENDIX II. EMISSION COEFFICIENTS DAIRY COWS

A. N-Excretion and N-Fertilizer level

A recent study (Baltussen et al. 1990) shows that there is a relation between the nitrogen excretion of dairy cows and the nitrogen level of grassland. The nitrogen level of grassland is, to a great extent, determined by the application of artificial fertilizer. Table 1 shows the relation for the Netherlands.

Table 1 Relation N-fertilizer and N-excretion.

N-fertilizer (kg/ha)	N-excretion (kg/cow)
168	158
264	176
359	200
457	212

This table is derived using a number of assumptions in Baltussen (1990) on the number of calves per dairy cow, the stall type, the size of the farm (26 ha), the milk yield per cow (6000 kg/year), the fodder composition, the number of animals per hectare (2.4/ha) and the pasture time. The relation between the total N level grassland and the n-excretion is shown in Table 2.

Table 2. N-excretion and total N-grassland.

N-level grassland (kg/ha)	N-excretion (kg/ha)
200	130
300	145
400	165
500	175

Part of the excretion is applied as manure on grassland (excretion in the stall period; 50% of the N is effectively applied). The N-excretion per dairy cow (including young cattle) is around 200 kg N, of which 82 kg in the stall period. Effectively 41 kg N (50%) is applied as excretion on grassland. Since the average N-application of fertilizer is 346 kg/ha the total N-application in the Netherlands is some 400 kg/ha (346 + 41). Table 3 shows the relation between N-level, N-excretion, N-organic effective and the N-fertilizer level.

Table 3. N-level, N-excretion, N-organic and N-fertilizer.

N-level (kg/ha)	N-excretion (kg/ha)	N-organic effect. (kg/ha)	N-fertilizer (kg/ha)
200	130	130/165*41 = 32	200-32 = 168
300	145	145/165*41 = 36	300-36 = 264
400	165	41	400-41 = 359
500	175	175/165*41 = 43	500-43 = 457

From Table 3, Table 1 can be derived. Of course one should note that the relation in Table 1 is a specific one based on specific assumptions for the Netherlands.

From Table 1 we can estimate the following function:

$$\text{N-excretion} = 126.22252 + 0.1932 * \text{N-fertilizer} \qquad (1.1)$$

This function has been used to estimate the N-excretion of dairy cows in other countries. The ratio between the N-excretion per dairy cow in the Netherlands and the other countries has been used to arrive at country specific emission coefficients for other countries.

The level of N-fertilizer use per hectare grassland in other countries in other European countries are estimated as follows. The total N-fertilizer consumption per country is distributed over arable land and grassland as 2:1. This ratio was based on the fertilizer levels advised in various countries (see Table 4)(CEC, 1989).

Table 4. Maximum advised N-fertilizer levels (kg N/ha/year)(1988).

	Meadow		Arable land	
	Grass	Silage	Barley	Winter wheat
Denmark	250	350	130	180
FRG	380	300	170	210
Ireland	390	325	140	210
Netherlands	400	400	-	200
United Kingdom	275	330	125	200

Taking the Netherlands as an example, we obtain the following. The N-fertilizer level was 240 kg N/ha. The area grassland was 45%, the area of arable land 55% of total agricultural land. This gives the formula:

$$0.45 * \text{N/grass} + 0.55 * \text{N/arable} = 240 \qquad (1.2)$$
$$\text{N/grass} = 2 * \text{N/arable} \qquad (1.3)$$

With:

N/grass being the N-fertilizer level of grassland.
N/arable being the N-fertilizer level of arable land.

For the Netherlands, this implies that N/grass is 330 kg/ha and N/arable land is 165 kg/ha. This corresponds quite well with the real N-fertilizer level on grassland of specialized dairy farms; their fertilizer level on grassland was 346 kg/ha in 1986/87 (Baltussen, 1990). Table 5 (next page) shows the N-fertilizer level that have been calculated using FAO statistics (FAO, 1989a; FAO, 1989b). Using formula (1.1) the N-excretion per dairy cow in other countries has been estimated (see Table 5, column 2). Table 5 also shows an index used to correct the ammonia emission coefficients for dairy cows in the Netherlands (column 3).

B. Meadow periods and emission coefficients

The second change that has been made was to take account of the differences in meadow periods in various countries. Using the information on the nitrogen balance for dairy cows in the Netherlands (De Winkel, 1988), in combination with data on the meadow period (Asman 1989) country specific emission coefficients we derived. For this purpose we used the following specification of the equations (see main text equations (2.1 to 2.4)) that relate the NH_3 emission coefficients to the N-excretion:

$$\text{N-stable} = 0.1324 * 17/14 * 54.44 * \text{stall period}/190 * \text{N-excretion}/100 \quad (1.4)$$

$$\text{N-application} = 0.25 * 17/14 * ((1 - 0.1324) * 54.44 * \text{stall period}/190 * \text{N-excretion}/100 \quad (1.5)$$

$$\text{N-meadow} = 0.12 * 17/14 * 84.52 * \text{meadow period}/175 * \text{N-excretion}/100 \quad (1.6)$$

In which:

N-stable	NH_3 emission coefficient stable
N-application	NH_3 emission coefficient application
N-meadow	NH_3 emission coefficient meadow
N-excretion	N in excretion in country i

Stall period and meadow period are the periods in each country. N-excretion/100 refers to the index used to estimate N-excretion in other countries with the Netherlands being 100. 0.1324, 0.25 and 0.12 are the coefficients for volatilization. 54.44 is the N-excretion in the stall in the Netherlands. 84.52 is the N-excretion in the meadow in the Netherlands. The resulting emission coefficients, as well as the length of the meadow period in each country, are presented in Table 5. In cases where no data on the stall period was available, the length was assumed to be 50% of the year (conform Buijsman et al., 1987).

Table 5. Dairy cows emission coefficients.

SECTOR COUNTRY	KG N PER PASTURE (kg/ha)	N EXCRETION PER COW (kg N/jaar)	N-EXCRETION INDEX (NL=100)	Stall period (days)	Meadow period (days)	Emission coefficients (Kg NH3/animal per year) stable	appli-cation	meadow	total
Albania	108	147	78	183	183	6.6	10.7	10.0	27.3
Austria	50	136	72	255	110	8.5	13.9	5.6	27.9
Belgium	185	162	86	115	250	4.5	7.5	15.1	27.1
Bulgaria	107	147	78	183	183	6.6	10.8	10.0	27.3
Czechoslovakia	153	156	82	150	255	5.7	9.4	14.8	29.9
Denmark	253	175	93	241	124	10.3	16.9	8.1	35.3
Finland	164	158	84	240	125	9.3	15.2	7.3	31.8
France	119	149	79	183	183	6.7	10.9	10.2	27.8
FRG	192	163	86	292	73	11.7	19.1	4.4	35.2
GDR	191	163	86	183	183	7.3	11.9	11.1	30.3
Greece	60	138	73	183	183	6.2	10.1	9.4	25.6
Hungary	153	156	82	180	185	6.9	11.2	10.7	28.8
Ireland	64	139	73	183	183	6.2	10.1	9.4	25.8
Italy	92	144	76	183	183	6.4	10.5	9.8	26.8
Luxembourg	185	162	86	180	185	7.1	11.7	11.2	29.9
Netherlands	325	189	100	190	175	8.8	14.4	12.3	35.5
Norway	208	166	88	120	245	4.9	8.0	15.2	28.0
Poland	122	150	79	183	183	6.7	11.0	10.2	27.9
Portugal	79	141	75	183	183	6.3	10.4	9.6	26.3
Romania	109	147	78	183	183	6.6	10.8	10.0	27.4
Spain	54	137	72	183	183	6.1	10.0	9.3	25.4
Sweden	118	149	79	135	230	4.9	8.1	12.8	25.7
Switzerland	39	134	71	183	183	6.0	9.8	9.1	24.9
Turkey	50	136	72	150	215	5.0	8.2	10.9	24.0
UK	111	148	78	180	185	6.5	10.6	10.2	27.3
USSR	24	131	69	183	183	5.9	9.6	8.9	24.4
Yugoslavia	49	136	72	183	183	6.1	9.9	9.3	25.3

APPENDIX III. EMISSION COEFFICIENTS SHEEP (AND GOATS)

Table 1. Sheep

SECTOR	Stall period (days)	Meadow period (days)	Emission coefficients (Kg NH3/animal per year) stable	appli- cation	meadow	total
COUNTRY						
Albania	91	274	0.33	0.60	0.98	1.9
Austria	0	365	0.00	0.00	1.30	1.3
Belgium	0	365	0.00	0.00	1.30	1.3
Bulgaria	91	274	0.33	0.60	0.98	1.9
Czechoslovakia	91	274	0.33	0.60	0.98	1.9
Denmark	91	274	0.33	0.60	0.98	1.9
Finland	243	122	0.87	1.59	0.43	2.9
France	91	274	0.33	0.60	0.98	1.9
FRG	152	213	0.54	1.00	0.76	2.3
GDR	91	274	0.33	0.60	0.98	1.9
Greece	91	274	0.33	0.60	0.98	1.9
Hungary	91	274	0.33	0.60	0.98	1.9
Ireland	91	274	0.33	0.60	0.98	1.9
Italy	91	274	0.33	0.60	0.98	1.9
Luxembourg	91	274	0.33	0.60	0.98	1.9
Netherlands	91	274	0.33	0.60	0.98	1.9
Norway	243	122	0.87	1.59	0.43	2.9
Poland	91	274	0.33	0.60	0.98	1.9
Portugal	91	274	0.33	0.60	0.98	1.9
Romania	91	274	0.33	0.60	0.98	1.9
Spain	91	274	0.33	0.60	0.98	1.9
Sweden	243	122	0.87	1.59	0.43	2.9
Switzerland	91	274	0.33	0.60	0.98	1.9
Turkey	91	274	0.33	0.60	0.98	1.9
UK	0	365	0.00	0.00	1.30	1.3
USSR	91	274	0.33	0.60	0.98	1.9
Yugoslavia	91	274	0.33	0.60	0.98	1.9
EUROPE						

Source: Van der Hoek for the N-excretion, N-retention and volatization for sheep. Stal period is assumed 1/4 year (91 days) unless data (Asman, 1990) for other countries were available.

Table 2. Goats

SECTOR	Stall period (days)	Meadow period (days)	Emission coefficients (Kg NH3/animal per year) stable	appli-	meadow	total
COUNTRY						
Albania	91	274	0.56	1.03	1.69	3.3
Austria	0	365	0.00	0.00	2.25	2.3
Belgium	0	365	0.00	0.00	2.25	2.3
Bulgaria	91	274	0.56	1.03	1.69	3.3
Czechoslovakia	91	274	0.56	1.03	1.69	3.3
Denmark	91	274	0.56	1.03	1.69	3.3
Finland	243	122	1.50	2.75	0.75	5.0
France	91	274	0.56	1.03	1.69	3.3
FRG	152	213	0.94	1.72	1.31	4.0
GDR	91	274	0.56	1.03	1.69	3.3
Greece	91	274	0.56	1.03	1.69	3.3
Hungary	91	274	0.56	1.03	1.69	3.3
Ireland	91	274	0.56	1.03	1.69	3.3
Italy	91	274	0.56	1.03	1.69	3.3
Luxembourg	91	274	0.56	1.03	1.69	3.3
Netherlands	365	0	2.25	4.13	0.00	6.4
Norway	122	243	0.75	1.38	1.50	3.6
Poland	91	274	0.56	1.03	1.69	3.3
Portugal	91	274	0.56	1.03	1.69	3.3
Romania	91	274	0.56	1.03	1.69	3.3
Spain	91	274	0.56	1.03	1.69	3.3
Sweden	122	243	0.75	1.38	1.50	3.6
Switzerland	91	274	0.56	1.03	1.69	3.3
Turkey	91	274	0.56	1.03	1.69	3.3
UK	0	365	0.00	0.00	2.25	2.3
USSR	91	274	0.56	1.03	1.69	3.3
Yugoslavia	91	274	0.56	1.03	1.69	3.3
EUROPE						

Source: emission coefficients van der Hoek (1989). This is based on on a stable period of one year. Data for other countries based on Asman (1989), partly. If no data were available it was assumed that the meadow period for goats is the same as for sheep.

APPENDIX IV. CONSUMPTION OF N-FERTILIZER TYPES

QUANTITIES

SECTOR COUNTRY	TOTAL FERTI-LIZER (TON)	ammonium sulphate	ammonium nitrate	ammonium sul nitrate	calcium ammonium nitrate	urea	ammonium phosphate	other nitrogen fert.	other complex fert.	other not spec.
Albania	66100		33050		33050					
Austria	165072	308			93924	1275		6043	63522	
Belgium	197758	4778		155	123511	698		5720	62896	
Bulgaria	418000									418000
Czechoslovakia	589000									589000
Denmark	381263	380	17333		82041	4432		90416	186661	
Finland	214353	5			21156	4442		6615	182135	
France	2568400	40900			1111900	287500		544700	583400	
FRG	1601435	116686		81261	1009775		84573	10709	298431	
GDR	773900	193475			286343	247648				46434
Greece	425000	56443	127466		53050	6610			181431	
Hungary	613827	296	224143		120743	171087		14682	82876	
Ireland	343000	3963	2403		130457	84690			121487	
Italy	1059044	67699	10517		195607	430506		26192	328523	
Luxembourg	197758	4778		155	123511	698		5720	62896	
Netherlands	458210	1394	0		364608	2467	1037	13558	75146	
Norway	113600					1300		15200	97100	
Poland	1335421	88885	787312		0	349279	71699	494	37752	
Portugal	148489	21844	0	3132	70474	6071	3372	853	42743	
Romania	720000								720000	
Spain	1147800	105006	38230	31004	311606	185332		72340	404282	
Sweden	240866	46	21974		51176	5126		66639	95905	
Switzerland	72600	1800	0		39900	17400	1600	400	11500	
Turkey	1110732	97263	217152		217152	246340	84376		248450	
UK	1314000		642260		33740			54000	584000	
USSR	11787000									11787000
Yugoslavia	521000								521000	
EUROPE	8375981	560953	6061603	117487	94794	1505229				

Source: FAO (1989, p.89). GDR based on Moeller et al.(1989).
Quantities for 1987/88. If no data available
then data of previous years was used.
Data of Buijsman (1985) was used to determine the
distribution between ammoniumnitrate and calcium
ammoniumnitrate. If no data were available a 50/50 split
was assumed (ALB, TUR).