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AMMONIA EMISSIONS TO AIR IN WESTERN EUROPE

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SUMMARY

Anthropogenic ammonia (NH_3) emissions to the atmosphere in western Europe (EEC + EFTA countries) are estimated to be between 2.8 and 5.2 Mt NH_3-N/year in the year 1990, with 4.0 Mt NH_3-N/year as best estimate. Waste from farm animals (cattle, sheep, goats, pigs, poultry and horses) is the principal source of atmospheric NH_3, as shown in Table 1.

Table 1 Origin and Quantity of Ammonia Emissions to Air in Western Europe in 1990

	Emission (Mt NH_3-N/y)	Range (Mt NH_3-N/y)	Origin (% of total)
Animal husbandry			
stables and manure	1.4		34
storage	1.3		32
manure spreading	0.3		8
grazing			
Subtotal	3.0		74
Fertiliser			
production	0.02		0.5
application	0.5		12.5
Leaf emission from crops	0.2		5
Miscellaneous	0.3		8
Total	4.0	2.8-5.2	100

The estimate of NH_3 emissions from animal husbandry is based on calculated and measured N excretions and losses, adjusted for national conditions when data are available. Fertiliser derived emissions are estimated from consideration of reactions between fertiliser compounds and soil, taking typical national characteristics of soil into account. Crops can both take up and emit NH_3 from the leaves; net emission is probably about 1.5 kg NH_3-N/ha/year, but can be larger when the weather during ripening is adverse. A variety of other minor sources also contribute to atmospheric NH_3: fur animals and other minor groups of farm animals, pets, exhalations from human beings, domestic use of ammonium products, refrigeration, combustion, treatment of waste water and disposal of sludge. Such emissions are included in "miscellaneous emissions".

The emissions can only be crudely estimated, as they vary greatly with circumstances. Thus the estimates for the Netherlands have a range of uncertainty of approximately 30%. The range of

uncertainty for other nations with fewer data useful for making emission estimates is probably even larger. The only source where the magnitude of NH_3 emission is accurately known is that of the fertiliser industry, as most plants measure the emissions and report them to authorities.

The estimate of NH_3 emissions in western Europe from the animal sector is about 15% higher than the lowest of other recent estimates. This is well within the range of uncertainty of such estimates. The estimate of total emissions is about 20 to 25% higher than other recent estimates as items not covered by most other estimates are included (crops and miscellaneous).

Published estimates indicate that NH_3 emissions in western Europe increased by about 50% between 1950 and 1980. The emissions probably peaked around 1990. There are no EEC regulations for NH_3 emissions, but national efforts and regulations are increasingly specifying rapid manure incorporation into soil after spreading; animal feed composition is better adjusted to avoid excessive N intake, and storage conditions for manures are being improved. Furthermore, fertiliser consumption is falling. Such measures should gradually reduce the emissions by about 20 to 30% of the 1990 level.

SECTION 1. INTRODUCTION

1.1 THE ISSUE

It is known that ammonia (NH_3) emissions to the atmosphere mainly originate from agriculture, especially from farm animals and their manures (Buijsman *et al*, 1986, 1987; Isermann, 1990a; Asman, 1992; Klaassen, 1992a,b).

Ammonia emission is an environmental issue because:

- NH_3 concentrations in the air in the vicinity of point sources (large animal husbandry units) can damage vegetation;
- increased aerial deposition of NH_3 and ammonium (NH_4^+) contributes to water and soil acidification and may be part of the complex of factors causing forest damage;
- NH_3 emissions are one of the principal sources for increased nitrogen (N) supply to natural areas; increased N supply to such areas can change the flora, contribute to eutrophication of terrestrial and aquatic ecosystems (e.g. the North Sea), and increase the fluxes of climate relevant gases (mainly N_2O) to the atmosphere.

These topics are reviewed by Ellenberg (1985); Istas *et al* (1988); Skeffington and Wilson (1988); Van Breemen and Van Dijk (1988); BML (1989); Malanchuk and Nilsson (1989); Fabry *et al* (1990); Bartels and Gehrmann (1990); Tamm (1991); Isermann (1993a); Sutton *et al* (1993) and Granli and Bøckman (1994).

Reports on the effects of NH_3 on man, animals, fish and plants have been issued by WHO (1986); the Institution of Chemical Engineers (1988); the US-EPA (1989); BML (1989) and the Fertiliser Institute (TFI, 1990). An assessment of NH_3 as a water quality factor has been published by Seager *et al* (1988).

The WHO/IPCS Environmental Health Criteria document on NH_3 (IPCS, 1986) discusses sources releasing NH_3 into the air. The document refers to estimates of such emissions published for the USA and the Netherlands, and states: "It must be emphasized that substantial uncertainties are associated with these estimates, which are given for rough comparison only." Further, the reports from the EMEP (co-operative programme for monitoring and evaluation of the long-range

transmission of air pollutants in Europe) (Iversen *et al* 1991; Sandnes and Styve, 1992) express a need for improved national emission estimates.

It is the purpose of this report to provide a more detailed estimate of these emissions than that given in the IPCS document and hence update this and similar documents in this respect.

1.2 BACKGROUND

The transformations of N between the many forms present in nature form a complex web of processes and reactions, the N cycle.

Man exerts a major influence on the N cycle through:

Agriculture

- soil usage (e.g. tillage, irrigation and drainage) that influence chemical and biological processes in the soil

- increased N input to soils through use of mineral fertilisers, growing of legumes (e.g. clover, beans, peas that can fix atmospheric N) and movement of N from one area to another through import of animal feeds

- animal husbandry, which plays a key role in transforming crops into products useful for humans, but also gives rise to large volumes of manures with associated N emissions.

Burning of fossil fuels in industrial, transport, military and civil activities. This generates N oxides that enter the N cycle as a general increase of nitrate (NO_3^-) input to soils and waters.

The N cycle has been reviewed by Söderlund and Rosswall (1982); Jenkinson (1990a,b) and Isermann (1993a) where further details can be found. A brief description of some of the processes in the N cycle is given in Appendix A.

Man-made changes in the N cycle raise environmental issues (Bøckman *et al*, 1990). ECETOC have earlier addressed one of these topics, nitrate in drinking water (ECETOC, 1988). The present report concerns another aspect of man's impact on the N cycle, namely NH_3 emissions.

NH_3 emissions are here defined as gaseous losses to the atmosphere.

NH_3 emissions as particulate substances to the atmosphere and to water are also mentioned when appropriate. However, NH_3, in the form of NH_4^+, is rather immobile in most soils because of ion exchange by clay particles and soil organic matter retards movement of NH_4^+ in soil, and NH_4^+ dissolved in soil water is prone to conversion to NO_3^- through microbial nitrification. There is thus insignificant leaching of NH_4^+ from soils. NH_4^+ bonded to soil particles may reach waters through soil erosion, and through run-off from intensive animal husbandry. Soil erosion is an important environmental issue, but outside the field covered by this report, as is NH_4^+ discharge to surface waters through sewage.

The topic of this report is NH_3 emissions in western Europe taken as the members of the European Community (EEC) together with European Free Trade Association (EFTA) members: Austria, Switzerland and the Nordic Countries of Finland, Norway and Sweden. Iceland is not included as it is so far out in the Atlantic that its small NH_3 emissions do not notably influence other European nations (Iversen *et al*, 1991). The reason for this restriction is that detailed information about sources is more easily available from the western than from the eastern parts of Europe.

NH_3 emissions in Europe is a complex topic, as agricultural practice and conditions for emissions vary with regions and countries. In order to bring out the main features without losing the details, the factors influencing emissions are discussed in the main text, while the national details are given in Appendix C.

1.2.1 Units and Nomenclature

NH_3 emissions are reported in the literature both as NH_3 and as NH_3-N. The form NH_3-N is used throughout the report. Literature data expressed as NH_3 have been converted to N using the conversion factor:

$$0.822 \times NH_3 = NH_3\text{-}N \qquad \text{(Eq. 1)}$$

In aqueous solution, NH_3 and NH_4^+ are related through the reaction:

$$NH_4^+ + H_2O \;\text{«}\; NH_3 + H_3O^+ \qquad \text{(Eq. 2)}$$

Below pH 8 (that is in almost all soils of agronomic interest in Europe) NH_4^+ is by far the dominant form. In this report the forms NH_3 and NH_4^+ are used according to which form is dominant in the process under discussion.

NH_3 concentrations in air are reported as $\mu g\ NH_3\text{-}N/m^3$ or $mg\ NH_3\text{-}N/m^3$ as appropriate. Conversion of ppm and ppb to mg/m^3 and $\mu g/m^3$ depends somewhat on temperature and pressure. The following calculation factors are used:

$$1\ ppm = 0.7\ mg\ NH_3/m^3 = 0.58\ mg\ NH_3\text{-}N/m^3 \qquad \text{(Eq. 3)}$$

$$1\ ppb = 0.7\ \mu g\ NH_3/m^3 = 0.58\ \mu g\ NH_3\text{-}N/m^3 \qquad \text{(Eq. 4)}$$

The concept of NH_3 emissions is used to describe net losses of NH_3 to the atmosphere from buildings, fields and crops. Circulation within enclosed systems (e.g. emitted from the soil but taken up by the crop canopy) is not regarded here as NH_3 emission.

1.2.2 Ammonia Concentrations in the Air

It has been known since 1804 that rainwater and thus air contains NH_3 (Sutton *et al*, 1993). NH_3 is present in air both as NH_3 gas and as its reaction product with acidic air components e.g. SO_2, giving NH_4^+ salts as aerosol and dissolved in droplets. These reactions are briefly discussed later in Section 4.2. Techniques for measuring NH_3 in air are reviewed by Kessel (1990). The subject of NH_3 and NH_4^+ in air has been reviewed by Warneck (1988); BML (1989) and Grünhage *et al* (1990).

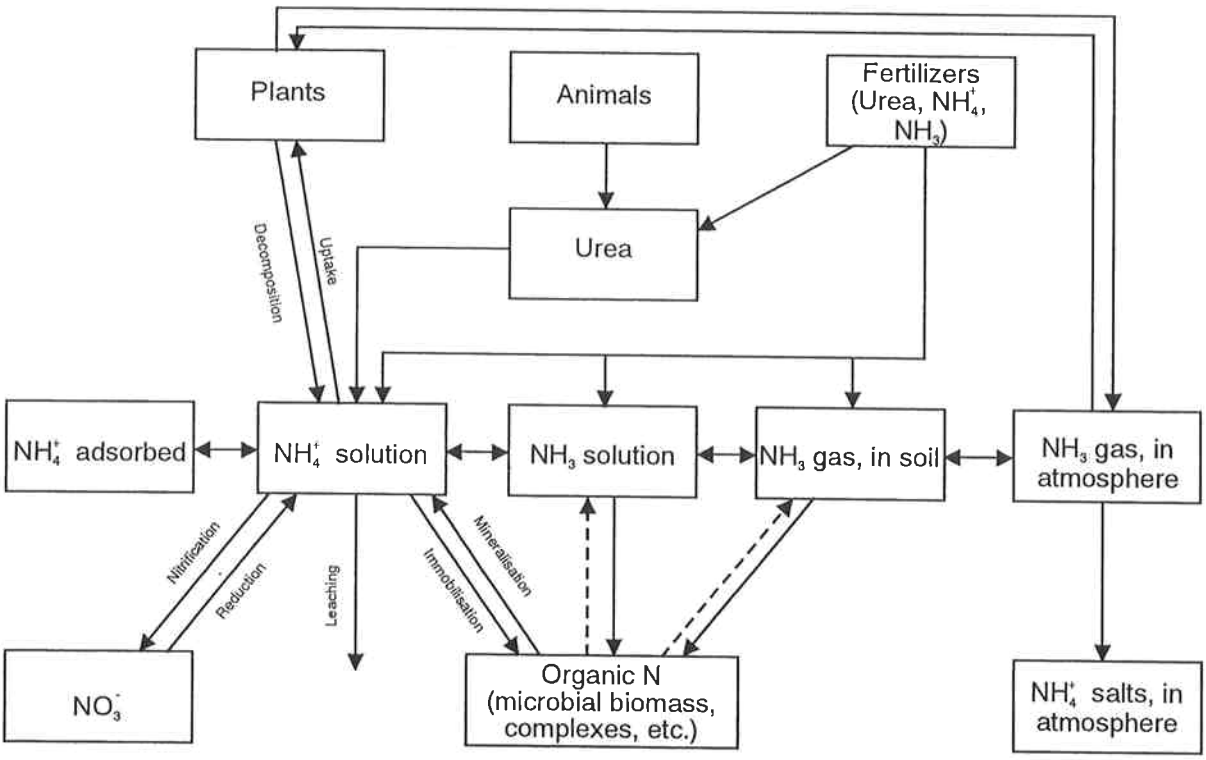
Concentrations over oceans and at high remote mountains are mostly below 1 $\mu g\ NH_3\text{-}N/m^3$. Concentrations over land are higher. Indoor concentrations in 10 homes in the UK averaged 36 $\mu g\ NH_3\text{-}N/m^3$ (Atkins and Lee, 1993). In urban areas concentrations of about 16 $\mu g\ NH_3\text{-}N/m^3$ are said to be typical (IPCS, 1986). Rural areas generally have lower concentrations within the range from 1-14 $\mu g\ NH_3\text{-}N/m^3$, with about 1-6 $\mu g\ NH_3\text{-}N/m^3$ as typical. Allen *et al* (1988) found that in rural areas in the UK, atmospheric concentrations were mostly around 2 $\mu g\ NH_3\text{-}N/m^3$. That urban areas have somewhat higher NH_3 concentrations than rural areas is supported by data listed by Atkins and Lee (1993). There are conflicting reports, as others find no difference between rural and urban air in this respect (Kruse *et al*, 1989). This topic deserves further investigation as urban areas may be an underrated source of NH_3. The concentrations tend to be higher in summertime than during winter. In areas of intensive animal husbandry NH_3 concentrations can be much higher, e.g. 50 $\mu g\ NH_3\text{-}N/m^3$ (Grünhage *et al*, 1990). Concentrations are commonly about 1 $mg\ NH_3\text{ - }N/m^3$ at a height

of 1-1.5 m above a field shortly after spreading of slurry (Bussink, 1993). Sensitive human beings can probably detect NH_3 at a concentration of about 2.2 mg NH_3-N/m^3, but most require a concentration about 27 mg NH_3-N/m^3 (46.8 ppm) to identify NH_3 by its odour (IPCS, 1986). The Occupational Exposure Limit (OEL) varies between countries, but are generally 15 mg NH_3-N/m^3 (18 mg NH_3/m^3 or 25 ppm, in Germany 50 ppm). Thus if the odour of NH_3 is noticeable, the concentration is too high. However, manure also emits other odorous materials (e.g. H_2S and organic substances) and perception of odour can not be used to measure NH_3 concentrations.

1.2.3 The Mechanism of Ammonia Emissions

This topic is reviewed in detail by Freney *et al* (1983) and Jayaweera and Mikkelsen (1990, 1991). A useful discussion is provided by Ross (1989). NH_3 is a gas at normal atmospheric temperatures and pressures, but with high solubility in water. NH_3 reacts with water and this reaction determines the concentration of NH_3 in the solution and hence the potential for NH_3 volatilisation. These relationships can be represented by Figure 1.

Figure 1 Some Biological and Chemical Reactions Affecting Ammonia Volatilisation (after Freney *et al*, 1983)



The NH_4^+ in soil originates as manures, fertilisers, and mineralisation (decomposition) of organic matter, e.g. plant residues. NH_3 can also be formed, e.g. in the rumen of animals and in the soil, by

bacterial reduction of nitrate, notably in environments rich in degradable carbon compounds (Cole, 1988).

NH_4^+ is removed from soil solution by three major mechanisms.

- Uptake by plants and microbes: Plants take up through their roots both NH_4^+ and NO_3^-, the relative uptake depends on availability, plant preferences, and soil conditions, e.g. soil pH. The practice of restricting N application to the growing season may serve to reduce NH_3 emissions. Increasing soil pH enhances plant NH_4^+ uptake (Mengel and Kirkby, 1987, p. 366). Soil microbes generally prefer NH_4^+ as their N source (Recous *et al*, 1990).

- Biological oxidation of NH_4^+ to NO_3^- occurs by the process known as nitrification (Prosser, 1986). Some N_2O and NO is formed and emitted to the atmosphere as a result of the oxidation. Several genera of bacteria (e.g. *Nitrosolobus, Nitrosomonas*) oxidise NH_4^+ to nitrite, which is further oxidised to NO_3^- by *Nitrobacter*. This set of reactions liberates protons:

$$NH_4^+ + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O \qquad \text{(Eq. 5)}$$

  The resulting acidification contributes towards a reduction in the potential for NH_3 loss through volatilisation.

  Nitrification is temperature dependent, there is little nitrification below 5°C and above 40°C, the optimum lies between 30° and 35°C (Van Burg *et al*, 1982). Nitrification contributes substantially towards reduced NH_3 emissions. If nitrification is inhibited with inhibitors (e.g. dicyandiamide, "didin"), NH_3 emissions can increase (Amberger, 1990), notably on calcareous soils unless the temperature is low so that volatilisation is reduced.

- By which, through ion exchange reactions, NH_4^+ can be retained in clays and organic matter. This reduces the concentration in soil solution (Mengel and Kirkby, 1987 p. 362). The binding to some clay minerals can be so strong that the NH_4^+ becomes largely unavailable to plant roots (Van Schreven, 1968). The capacity of the soil for ion exchange (cation exchange capacity) is one of the soil factors influencing NH_3 volatilisation.

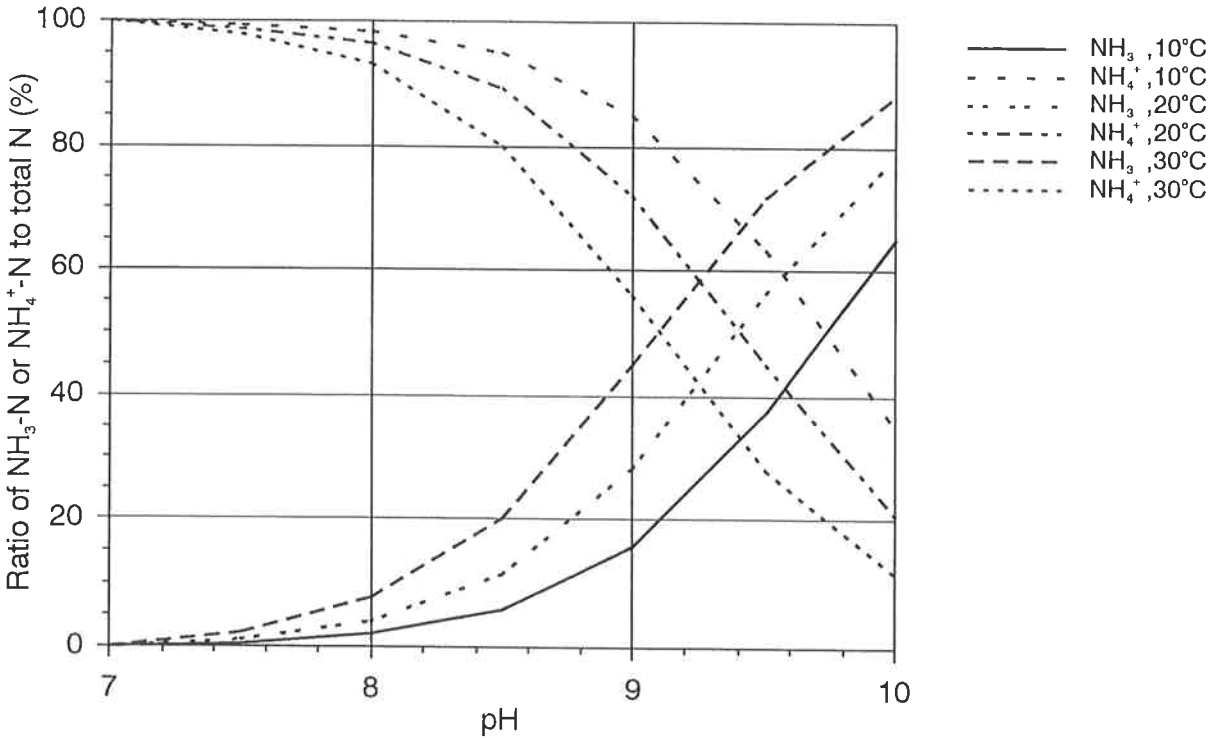
As a result of these processes NH_4^+ added to soil (as manure, fertilisers) or produced from decaying manures, crop residues and soil organic matter is transformed within a few days. Enhanced NH_4^+ concentration in soil due to such additions is therefore a transient condition.

NH_4^+ in aqueous solution is in equilibrium with NH_3, the relative concentrations are determined by the pH and the temperature (Equation 2).

The equilibrium constant (pKa) for this acidic dissociation is 9.7 at 10°C; 9.4 at 20°C and 9.1 at 30°C (Bates and Pinching, 1950).

Figure 2 illustrates the relative concentrations of NH_3 and NH_4^+ in water at different pH at these temperatures.

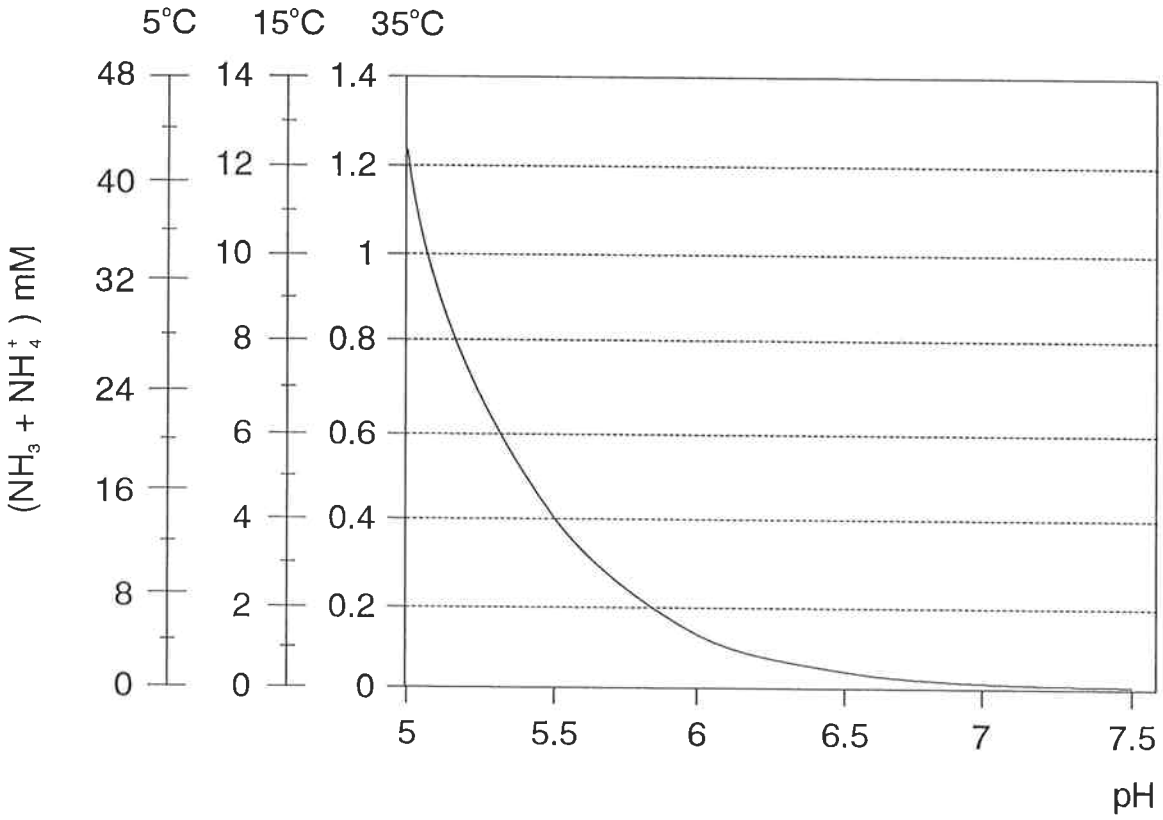
Figure 2 Relative Concentrations of NH_3 and NH_4^+ in Water at Different pH and at 10, 20 and 30°C (after Bates and Pinching, 1950)



Henry's law permits the calculation of the ammoniacal (NH_4^+ + NH_3) concentration in aqueous water solution in equilibrium with NH_3 in air at various temperatures. Slightly different versions are used in the literature for this relation. This topic is discussed by Fjeldberg and Bøckman (1994). The relationship recommended by Edwards *et al* (1978) is used for the construction of Figure 3 that

represents this relationship for aqueous NH_3 in equilibrium with air with a typical summertime concentration of NH_3.

Figure 3 NH_3 Concentration for a Solution with Different pH in Equilibrium with Air Containing 2 μg NH_3-N/m^3 at 5, 15 and 35°C



When the concentration is higher than that given by the curve, NH_3 can in principle be lost through volatilisation from the solution.

Since animal waste slurry has a pH of 7 to 8 and contains 1 to 3 g NH_3-N/l, the potential for NH_3 emissions are high.

When NH_3 is lost through volatilisation, the solution becomes less alkaline, this will counteract further losses. It follows that emissions can be higher when the buffer capacity of the soil is large enough to counteract this acidification (Freney *et al*, 1983).

NH_3 emissions also depend on soil reactions. A high cation exchange capacity (soils rich in clay or organic matter) will reduce the NH_3 concentration in the soil solution and thus the emissions (Freney *et al*, 1983).

NH_3 volatilisation does not only depend on chemical factors. Physical factors are also important (Freney *et al*, 1983). Votalisation is restricted by diffusion barriers to transport of NH_3 to and across the water/air interface (Jayaweera and Mikkelsen, 1990). Increasing wind removes NH_3 from the surface and can enhance emissions as does increasing temperature. NH_3 volatilisation therefore varies with the weather: rain dilutes the soil solution and can transport soluble ammonium salts deeper into the soil; dry spells can cause ammonium salts to be transported towards the surface through capillary transportation with evaporation (Kirk and Nye, 1991a,b).

1.2.4 Techniques for Measuring Ammonia Emissions

Both field studies and measurements of emissions from samples kept in a laboratory have been used. Generally results from field studies are preferred for estimation of emission factors. Laboratory studies are useful but conditions can differ markedly from those in the fields (e.g. temperature and air humidity) and laboratory studies seems to give somewhat higher NH_3 emission levels than comparable field studies.

Various methods are now available for measuring NH_3 emissions (Kessel, 1990; Sutton *et al*, 1993).

This topic was discussed at a recent symposium (KTBL, 1990). Methods using wind tunnels or otherwise enclosed chambers are useful (Ferm, 1983), but do not adequately reflect climatic (especially wind) conditions, unless steps are taken to keep the flow in the tunnel about equal to the wind in the open. With this precaution results from wind tunnel experiments can be reliable. Micrometeorological methods (Denmead, 1983; Wilson *et al*, 1983; Fowler and Duyzer, 1989) give the most realistic measurement of field emissions (Ferguson *et al*, 1988). Three different techniques have been used for measurement of NH_3 emissions: eddy correlation, gradient diffusion and mass balance methods. The first 2 are limited to extensive and uniform land areas. Measurement of emission from grazing is restricted to the latter method, based on measurement of concentration differences between the edge and the centre of the field. Both automated thermodenuders and simple passive samples for measurement of NH_3 in the air are now available (Keuken *et al*, 1989; Sherlock *et al*, 1989; Andersen, 1990; Schjørring *et al*, 1990, 1992). However, field studies are labour intensive and expensive.

Wind tunnel and micrometeorological methods both have advantages and problems. The many factors influencing NH_3 emissions from soil vary, both during the day, between day and night, between days, between weeks, and notably between seasons. These variations should be borne in mind when estimates of the fate of NH_3 are made and discussed.

Plants introduce a further complication. Living plants can both take up and emit NH_3 through their leaves. Thus in a crop, all NH_3 that is evaporated from the soil is not necessarily lost from the field. This must be borne in mind when results from bare (fallow) soil and from pot experiments are evaluated. This topic is further discussed in Section 3.4.

1.3 PREVIOUS REVIEWS OF AMMONIA EMISSIONS IN EUROPE

The principal reviews of this topic are those of Buijsman *et al* (1986, 1987); Asman (1992) and Klaassen (1992a). The results of Buijsman *et al* have been used as the basis by other authors (Eliassen *et al*, 1988; Bartnicki and Alcamo, 1989; Fabry *et al*, 1990; Isermann, 1990a,b; Klaassen, 1992b). Buijsman *et al* have later stated that they regard their estimates published in 1986 and 1987 as too low, and that they should be increased through multiplication with the factor 1.2 (Eliassen *et al*, 1988). With this correction the estimate of Buijsman have formed the basis for the estimates used by EMEP in their models (Iversen *et al*, 1991; Sandnes and Styve, 1992). Whenever the data from the reports by Buijsman *et al* (1986, 1987) are referred to, they have been corrected in this manner. Earlier estimates (from before 1980) are listed by Buijsman *et al* (1986), and were in general agreement with their results. These early studies have now mainly historical interest and will not be further discussed here.

Isermann (1990a) has surveyed emission factors and reports of NH_3 emissions for north-western Europe with emphasis on Germany and Katsoulis and Whelpdale (1990) present a short overview for south east Europe.

Others have made similar estimates for NH_3 emissions for various European nations. These estimates are discussed in Section 4.1.

All estimates are made by the same method: sources (e.g. farm animals with their resulting manures, mineral fertilisers production and use) are identified, quantified and then multiplied with an emission factor. This emission factor is the estimated loss of NH_3, in % of total amount present in the source. While the basic principle is the same for all studies, they do differ in the details and the number of minor sources included in the surveys.

Through the use of this method Buijsman *et al* (1986, 1987) estimated total European (including Turkey and the western part of USSR) NH_3 emissions in the early 80's as 6.4 Mt of NH_3-N (corrected for a 20% under-estimate). The sources were: livestock wastes, 81% of total; fertiliser

use, 17% of total; others, 2% of total. Details of their assessment for emissions from western Europe are given in Table 2.

Table 2 Anthropogenic Ammonia Emissions in Western Europe in the Early 80's
(Buijsman *et al*, 1986, corrected values[a])

Countries	Livestock waste (kt NH_3-N/y)	Fertiliser (kt NH_3-N/y)	Total, incl. industrial sources (kt H_3-N/y)	Emission density[b] (kg N/ha agricultural area)
EEC				
Belgium	74	4	82	58
Denmark	87	23	111	40
Eire	110	5	117	21
France	569	130	709	23
Germany	488	77	578	32
Greece	69	25	95	17
Italy	252	101	361	21
Luxembourg	4	<1	5	39
Netherlands	128	12	150	74
Portugal	38	7	47	10
Spain	177	49	232	9
UK	307	90	405	22
EFTA				
Austria	62	9	72	20
Finland	38	4	44	17
Norway	27	7	36	36
Sweden	46	6	52	15
Switzerland	49	4	53	26
Western Europe	2,525	554	3,149	21

a By coincidence, when the numbers are corrected (factor 1.2) and transformed from NH_3 to NH_3-N basis (factor 0.822), they remain unchanged in magnitude

b Emission density is calculated from agricultural emissions and agricultural area (including permanent pastures)

The principal problem with this method for assessing NH_3 emissions is the estimation of emission factors.

The location and magnitude of the sources for NH_3 emissions are usually accurately known, e.g. number and types of farm animals in a given district and types and amounts of fertilisers used.

Nevertheless the emission of NH_3 from, say, a dairy cow farm will depend on factors such as feed composition and N content, housing conditions, methods for collecting urine and droppings; time, conditions and method for manure spreading, time spent in stable or at pasture, grazing management, and weather conditions. Further, farms are not uniform in facilities and management. It is therefore not surprising that measurements of NH_3 emission factors vary widely, e.g. published emissions of NH_3 from manure spreading vary from almost nil to almost all.

The estimation of emission factors will be discussed later, for each source for NH_3 emissions. However, assessments of NH_3 emissions are approximate. This is stressed by Buijsman *et al* (1986) but not always by the users of their results.

Buijsman *et al* (1986, 1987) state that the overall uncertainty in their assessment could be approximately 30%. Thus their (corrected) estimate of total western European emissions of NH_3 is that it is probably within the range of 3.1 ±0.9 Mt NH_3-N/year (Table 2).

Möller and Schieferdecker (1989) estimate the uncertainty of NH_3 emission assessments to some 40%. Kruse *et al* (1989) refers to a range of approximately ±20% of calculated emission values as a reasonable estimate, Asman (1990) estimates the uncertainty in his detailed estimate for Denmark to at least 30-40%. These estimates of ranges of uncertainties are not substantiated by published calculations, but serve mainly to emphasise the very substantial uncertainty with the estimates.

It is in this perspective that assessments of NH_3 emissions from European agriculture and industry must be seen. It should be possible to refine the estimate of emissions somewhat by a more detailed analysis of the available material, but a high degree of uncertainty will remain.

The indications are that anthropogenic NH_3 emissions in Europe dominate over natural background emissions, but it is not known what the atmospheric budget for NH_3 in Europe was in prehistoric times. Buijsman *et al* (1986) refer 2 estimates of approximately 70% and 90% as the present anthropogenic contribution to atmospheric NH_3 and Isermann (1993a) suggests that more than 90% of all NH_3 in the atmosphere of western Europe is of anthropogenic origin.

Estimates published by Buijsman (1986); Asman *et al* (1987) and Asman and Drukker (1988) are that the European (excluding former USSR area) anthropogenic emissions were about 2.0 Mt NH_3-N in 1870; 2.3 Mt in 1920; 2.7 Mt in 1950 and 4.3 Mt in 1980.

In the Netherlands NH_3 emissions have probably increased by a factor of 2.5 between 1950 and 1980 due to increased livestork numbers and increased animal productivity (ApSimon *et al*, 1987).

Denmead (1990) has published detailed information about NH_3 emissions to air in Australia, where 49% of atmospheric NH_3 was from natural fields with a small contribution from wildlife. The anthropogenic emissions came from domestic animals (67%), biomass and coal burning (20%) and fertilised fields (13%).

Estimates of global NH_3 emissions have been made by Warneck (1988) who suggested 54 Mt NH_3-/year while Schlesinger and Hartley (1992) assessed the global flux to be approximately 62 Mt NH_3-N/year. The sources according to their estimate are in Table 3.

Table 3 Sources of Global NH_3-N Flux (Schlesinger and Hartley, 1992)

Source	Flux (Mt/y)
Domestic animals and their manures	26
Oceans	11
Unmanaged ecosystems	8
Fertilised agricultural soils	7
Biomass burning	4
Other sources such as human waste, coal combustion	6
Total	62

However, Crutzen (1983 as quoted by Denmead, 1990) cites arguments that point to biomass burning as the principal single source of anthropogenic NH_3 in the atmosphere on the global scale.

1.4 THIS REVIEW

The literature published and abstracted to the end of 1992 has been covered. Due to delay in abstracting, the literature published in 1992 may be incomplete. More recent papers have been included as far as available, but the fact-finding part of the editorial work was mostly completed during 1992.

1990 was selected as the basic year for discussions, though in some cases data from 1988 or 1989 are used where 1990 data were not available.

SECTION 2. EMISSIONS OF AMMONIA FROM THE FERTILISER INDUSTRY IN WESTERN EUROPE

Emissions of ammonia from the fertiliser industry are the only anthropogenic NH_3 emissions that are accurately known, but they form an insignificant part of the total. Current knowledge within the industry about NH_3 emissions is presented in greater detail than warranted by their importance, as the published information about this topic is outdated and inaccurate.

The fertiliser industry is practically the sole world-wide industrial producer of NH_3. The world production peaked at approximately 100 Mt of N at the end of the 80's and has been declining since. About 80% was and is used for production of fertilisers. The rest, in the form of NH_3 and the derived nitric acid, is used in a wide range of industries, notably in the production of explosives and polymers. The western European production of NH_3 and consumption through N containing fertilisers is about 12% of the world total.

This discussion will be limited to the manufacture of NH_3 and N containing fertilisers. Emission from other uses will be discussed in Section 3.5 on other anthropogenic sources.

There are 2 main types of industrial NH_3 emissions to the atmosphere. One is straight NH_3 gas and the other is dust or particles containing NH_4^+ or urea originating in various stages of fertiliser manufacture, the most important being neutralisation, granulation, prilling or drying. Storage loss, be it NH_3 gas, or N containing dust, is negligible.

During the years 1970-1990 a great amount of restructuring in the whole of the European fertiliser industry took place, coupled with a marked effort to reduce all emissions, be it to air or water. These trends are ongoing and are appearing in some parts of the former Eastern European countries where they are expected to gather momentum in future.

What has been achieved up to now has been done through:

- development of new or improved processes for treatment of effluents,
- development of new production processes and of improved equipment design to ensure better energy efficiency, improved safety and reduced emissions,
- introduction of these improvements into existing production facilities,

- outright closure of old plants, often associated with outdated technology and considerable emissions,

- building new plants to modern emission standards.

The estimate of NH_3 emissions from the fertiliser industry for 1988 is based on a study carried out by EFMA (European Fertiliser Manufacturers Association) for presentation to regulatory agencies handling environmental issues. The results have been given to authorities, but as the full report contains proprietary information on certain plants, it is not open to the public. A summary of this report is given in Appendix B.

It can be seen that emissions vary widely. This is mainly due to the different production processes used by the industry, age of plants and different emission abatement techniques used for off-gas treatment. Often off-gas or tail-gas treatment is an add-on equipment to an existing older plant. This has lower efficiency than any abatement technique incorporated in a new plant.

On the whole, the fertiliser industry in western Europe loses about 19 kt/year of gaseous NH_3-N to the atmosphere for an end production of fertiliser N of more than 10 Mt. That is approximately 0.5% of the anthropogenic emissions (Table 1).

For most plants detailed measurements of emissions are available, and emissions for about 70% of the production volume are known. It is thus known that western European fertiliser industry emits 13 kt NH_3-N/year to the atmosphere. These measured emissions form the basis for the estimate that a further 6 kt NH_3-N/year is emitted by those parts of the industry that are not covered by detailed measurements. It should be noted that former Eastern Germany is not included due to lack of data.

On average the emission is 1.786 kg N/t N of total N in finished fertiliser.

Emissions differ markedly between the various products, as shown by the ranges of emission factors (Table 4).

The EFMA survey found a substantially lower emission than the estimate of Buijsman *et al* (1986) of 62 kt N/year. Their estimate was based on an average NH_3 emission of 4.1 kg N/t N (5 kg NH_3/t N) on what the authors regarded as crude data, only used because no better were available.

Table 4 Emission Factors for Different Types of Fertiliser Plants

Product	NH_3-N emission (kg N/t N produced)[a]	Range (kg N/t N)
Ammonia	0.005	-
Ammonium nitrate	0.245	0.01 - 0.4
Calcium Ammonium Nitrate	1.128	0.13 - 2.44
NPK Fertilisers	2.539	0.01 - 7.68
Nitric acid	0.038	0.02 - 0.19
Urea	4.179	0.57 - 7.68

a Weighted average

The present emission estimate partly reflects the improved data base, partly the results of restructuring and technical improvements in the industry in the last 15 to 20 years.

In order to produce a fertiliser based on ammonium, NH_3-N goes through several transformation steps before the final product is obtained. This gives emissions at each step. To produce the 10 Mt of N contained in the final product, the industry has to "handle" 24 Mt of various nitrogenous products. In this case the avarage emission factor would be 0.782 kg N/t N processed.

Following production the fertiliser is stored and distributed. Emissions of NH_3 to the atmosphere from these operations are negligible compared to those during production.

Appendix B also lists dust emissions from fertiliser production as background information. Western European fertiliser industry emits approximately 9 kt N/year as particulates to the atmosphere. This is somewhat less than half of the gaseous NH_3 emissions. The emitted dust rapidly settles out in the neighbourhood of the plant. It can represent a local nuisance and as such be subject to regulations, but should behave as other applied fertilisers. In view of the low losses of NH_3 from applied fertilisers and the small amounts emitted, this dust does not represent a significant source for atmospheric NH_3.

SECTION 3. AMMONIA EMISSIONS FROM AGRICULTURAL AND ANTHROPOGENIC SOURCES

3.1 GENERAL BACKGROUND

There is general agreement that most NH_3 emitted to the atmosphere in western Europe originates from farm animals and their waste. Other sources, e.g. fertiliser application, are minor in comparison. An understanding of the causes of NH_3 emissions from agriculture is desirable for a discussion of present emission levels and their possible reduction. The conditions and processes that lead to NH_3 emissions will therefore be discussed at some breadth. Further details can be found in Appendix C.

3.2 AMMONIA EMISSIONS FROM FARM ANIMALS AND THEIR WASTE

3.2.1 Farm Animals in Europe

Animal husbandry has always been an important part of agriculture. Animals transform feedstuffs that man can not use (e.g. grass) or that are cheap (e.g. corn, soybeans) into high-value products such as meat, milk, eggs, wool, furs, hides. The large loss of NH_3 from livestock systems is due to the low conversion of dietary N into animal protein: usually more than 75% of N intake is excreted in forms that give rise to NH_3 emissions (Jarvis and Pain, 1990). European agriculture has seen great changes since the end of the second world war. Productivity has greatly increased, but has levelled off in recent years as self-sufficiency with food has been mostly reached and then exceeded. In some societies animal traction power is still important in agriculture, but in Europe horses are now mainly used for sport. Western Europe has changed from being a region dependent on food imports with strict food rationing and areas with semi-starvation, to a region with food abundance and production in excess of needs and available for export (Bøckman *et al*, 1990). However, EEC production of animal products is in most cases only slightly above the self-sufficiency level (Table 5).

The most marked change in the animal population since 1950 is in the number of pigs, this has increased by about 250%. The expansion in the poultry industry is also marked. Further, there has been some increase in the number of cattle (about 25%), but only small changes in the number of dairy cows, and sheep. The number of horses has declined. Farming has become more specialised, e.g. with pig farming concentrated in certain districts, and with large areas of arable farming with few animals.

Table 5 EEC Self-Sufficiency with Animal Products (1988). (Eurostat, 1990)

	Human consumption (kg/head/y)	Self sufficiency (%)
Meat and eggs (EEC 12)		
Adult cattle	20.3	102.5
Veal	2.3	117.2
Pork	39.7	103.3
Sheep, goats	3.8	82.9
Poultry, meat	17.6	105.1
eggs	16.4	101.2
Milk products (EEC 10)		
Fresh milk	100.5	100.9
Cream	3.3	103.7
Concentrate, milk powder	3.6	216.7
Butter	5.9	91.2
Cheese	14.9	106.4

Systematic animal breeding has given high-yielding animals. Use of prophylactics (vaccination, antibiotics in feed and for treatment of diseases) and hygienic measures (enclosed stables where rodents, birds and insects that spread diseases can be controlled) have made it possible to keep large herds of animals under environmentally controlled conditions at high stocking densities.

The feed has also changed. Present day feed in some cases is more N efficient than formerly. For example, in the Netherlands the N intake of feed for a pig between 25 and 100 kg was 7.9 kg N in 1970, today it is 6.6 kg N (LEI and CBS, 1972, 1991).

The effect of these technological and structural changes in animal husbandry can be seen from productivity data. Thus while the diary cow population has remained almost constant, the milk yield per animal and total production has almost doubled since the end of World War II.

The emission per country is related to the total amount of N excreted in faeces and urine. This total amount can be determined from the number of animals (from EUROSTAT or national statistics) and the average N excretion per animal. The latter can be estimated. NH_3 emissions occur from the shed, manure, storage, application and from grazing. If the emission coefficients of these loss paths are known then the total emission can be calculated. The emission coefficients used in Appendix C are based on emission measurements. Many emission data based on experiments are

known for the Netherlands, Germany and the UK. Emission coefficients can be determined from these data. If there are none or limited data available for the other countries, the emission data from these 3 nations are used as a basis for the estimate.

3.2.2 Nitrogen Transformations Associated with Farm Animals

Much of the crops in the industrialised nations are used as feed for farm animals. In the UK about 80%, in Germany 83% and in the Netherlands and in Norway 94% of the N in the domestic crop production is in that part used for animal feed (Bøckman *et al*, 1990; Isermann, 1990a, 1991).

The N compounds in the feed are metabolised and used to maintain the organism, for growth and for reproduction. Metabolic waste and intake of N compounds in excess of need is excreted. The N efficiency varies with feed quality, and with type of animal production. Most of the N is excreted: bulls on pasture, 87-93%; dairy cattle, 80%, feeder pigs (grain fattening), 73-82%, (in % of total N in feed), (Isermann, 1990a). There can be significant seasonal variations in the amounts of N excreted by cattle, because the N content in intensively managed pasture can be higher than that usual for winter feed given in stables.

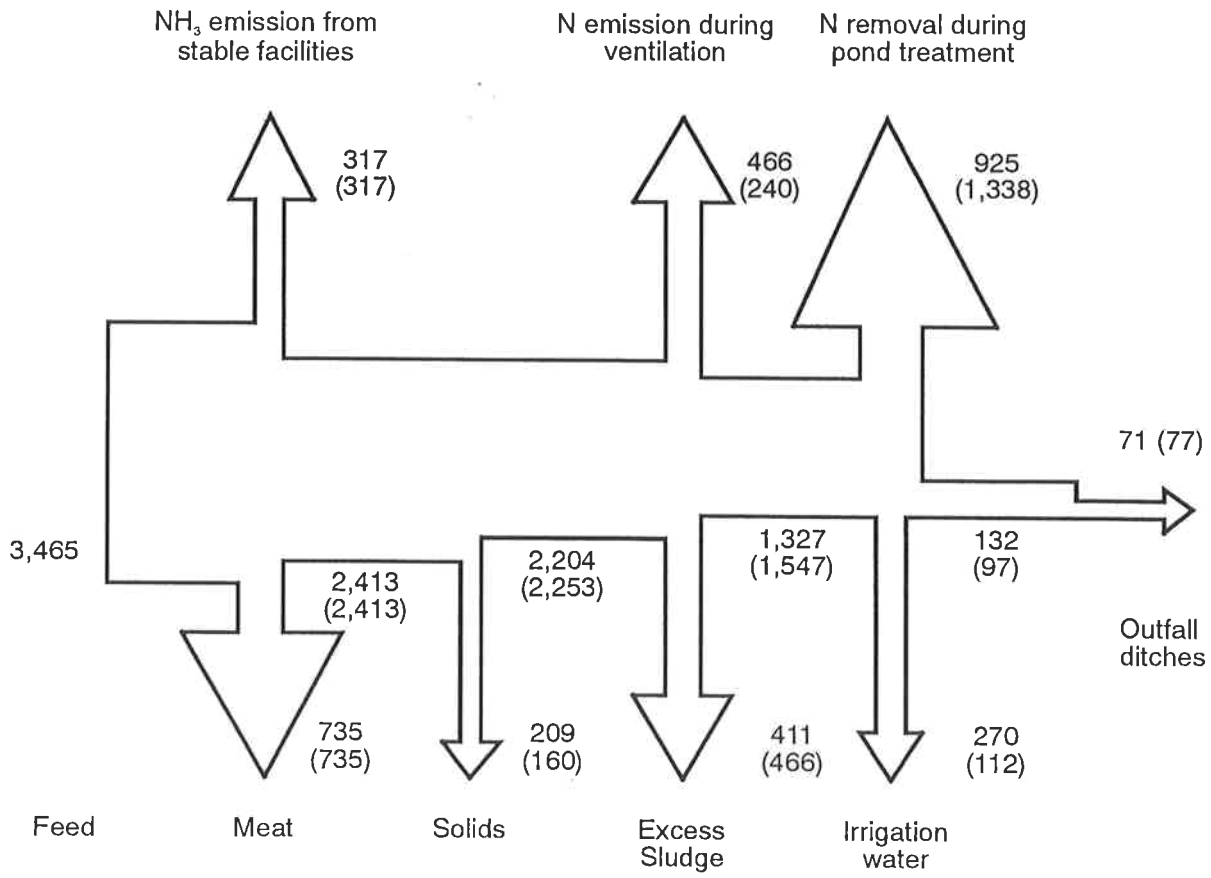
A substantial part of the excreted N is lost as NH_3 emissions to the atmosphere. This is illustrated by data (Figure 4) from a N balance study at a large feeder pig farm in Eastern Germany (Isermann, 1990a).

The increased productivity of the individual animals discussed in Section 3.2.1 means that each high-yielding animal excretes more N than their less productive predecessors. But their high productivity also implies that less N is used for the maintenance of the basal metabolism of the animal for each unit of product made, and thus for example the N excretion per kg milk has decreased. This is illustrated by dairy cows (Table 6).

Thus high productivity of individual animals is a factor contributing towards minimising the NH_3 emissions at a given national production level provided the animals are not given excessive amounts of N in the feed, but the increased emission per animal can result in high local emissions when the animal density is high.

N is excreted mostly in urine. For cattle about 70-90% of urine N is excreted as urea, the remainder as allantoin, hippuric acid and creatine/creatinine (Doak, 1952). Some N is also present in droppings as microbial cell constituents and in undigested food. Excreted urea is rapidly (within days) hydrolysed to NH_3 through the action of microbial urease.

Figure 4 **N Flow (t/y) in the Feeder Pig Facility[a] Neustadt/Orla in 1988 and (1989).** (Kehr, 1990)



a Stock level 175,026 (169,759) pigs

Table 6 **N Excretion/Animal/kg Milk Produced for Various Yield Levels[a]**

Milk yield (kg milk/y)	N excretion (kg N/animal/y)	N excretion (g N/kg milk)
4,500	107	23.9
6,000	121	20.2
7,500	135	18.0

a With feed containing 18% crude protein (optimal digestibility). Values calculated from Equation 1, Appendix C)

The rate of this hydrolysis depends on temperature, pH, amount of urease present, and soil water content. The hydrolysis is likely to be slow at low temperatures and on dry soils (Lantinga *et al*, 1987; Lockyer and Whitehead, 1990). The hydrolysis increases the pH from around 7 up to as high as 9.2. When urine is collected together with dung as slurry, pH is generally 7 to 8.5. The pH of

slurry can be lowered by addition of acids, but this is costly, causes foaming and increases the emissions of H_2S.

The decomposition of protein in faeces is usually a slow process, but during storage of slurry the composition moves towards 40 to 70% of total N being present as NH_4^+-N (Van Faassen and Van Dijk, 1987).

In poultry manure uric acid and proteins are the main N components. To release NH_3 uric acid has to be decomposed to urea, which can then be hydrolysed. Therefore the rate at which NH_3 is released is lower than for urea (Groot Koerkamp *et al*, 1990) and poultry manure can be rapidly dried with low NH_3 losses (Oosthoek *et al*, 1990).

Slurry composition and amounts formed vary somewhat, but Dutch values can be taken as an illustration. One dairy cow (7,000 kg milk·year) gives 24 t/year slurry with 9.5% dry matter and 2.3 kg NH_3-N/t (wet weight); 10 pigs give 21 t slurry/year with 6.6% dry matter and 4.4 kg NH_3-N/t (Asijee, 1993).

The amount excreted depends on the food composition. Animal feed is produced to defined specifications in order to ensure rapid growth and development, high yields and good health. The feed composition can be further improved to enhance N efficiency and reduce N excretion while maintaining high yields (Spiekers and Pfeffer, 1990), but at some cost.

There is a basic difference in utilisation of the feed between ruminants and monogastric animals (Kirchgessner, 1987; Sundstøl, 1990). In ruminants (cattle, sheep) most of the protein in the feed is decomposed to simple N compounds (e.g. ammonia) by microbial processes in the rumen. The microbes use these compounds for the synthesis of microbial protein. It is this microbic protein that is digested further down the alimentary system. Though some protein passes unchanged through the rumen, the rumination process ensures that the amino acid uptake by ruminants is largely independent of the feed composition.

The protein synthesis in the rumen depends mainly on 2 factors: supply of digestible carbohydrates and availability of N, especially NH_4^+. For a balanced synthesis of rumen protein the ratio of these 2 factors should be about 29 g N/kg digestible carbohydrates. If NH_3 is present in excess of this it will be taken up, metabolised to urea in the liver and excreted with urine. It is therefore in principle possible to reduce the amounts of excreted N to a practical minimum for the relevant yield (e.g. milk) level by paying attention to the proper ratios between the content of degradable protein

quality, and the content of digestible carbohydrates in the feed. When the feed has a rather high N content (e.g. is rich in clover or alfalfa), the N excretion can be reduced by giving supplementary feeds based on cereals low in protein.

Monogastric animals (e.g. pigs, horses, poultry) depend on the protein present in their feed for their supply of essential amino acids. These are those amino acids the animal is unable to make themselves, or make at so slow rate that they depend on input from the feed for most of their body's needs (Kirchgessner, 1987). The feed should preferably have a composition of digestible protein that is close to that of the over-all body daily need for individual amino acids. If the protein composition is markedly different from the ideal, more protein must be given to ensure that the body needs are satisfied for those amino acids that are in short supply. These are usually lysine, threonine and methionine. Protein in excess is metabolised for energy and the N excreted.

N excretion also depends on the digestibility of the protein: if this is poor, the N content of the droppings will increase.

Thus attention to the feed quality and composition can reduce the amount of food needed and amounts of N with the animal waste. Feeding tables (eg in Norway) are being revised to reduce the amounts of N excreted by the animals.

3.2.3 Ammonia Emissions from Animal Stables, and from Waste Collection and Storage

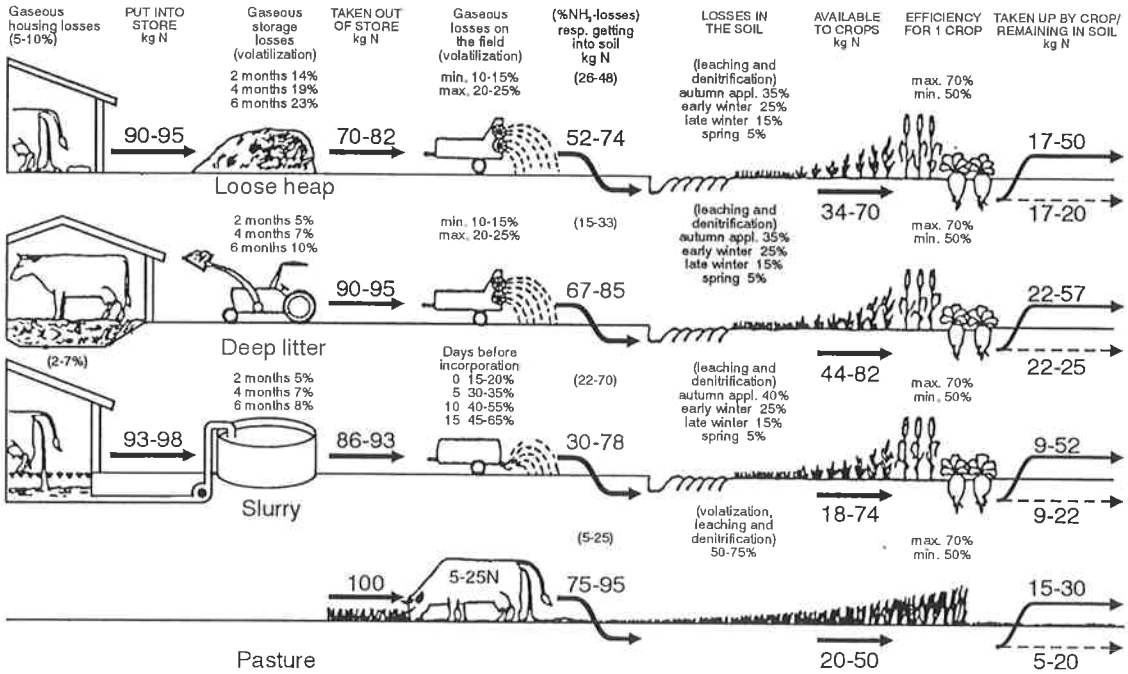
3.2.3.1 Stabling Conditions

Traditions for animal housing and methods for collecting and storing manure vary between countries and farms. Figure 5 provides a simple introduction to the main types of stabling and husbandry practices for cattle, and the associated NH_3 emissions.

3.2.3.2 Ammonia Emissions from Stables

About half of all NH_3 emission from farm animals and their waste comes from stables and storage for manures and slurries. NH_3 and other odorous substances are emitted from the stables with ventilated air, and from exposed storage of manure and slurry (Hartung, 1992). The potential for NH_3 emissions increases with (Nilsson, 1986; Fabry *et al*, 1990):

Figure 5 Stabling and Manure Collecting Systems and their N Efficiency on a Dairy Farm (Isermann 1990a, after Ministerie van Landbouw en Visserij, 1985)



- Increasing residence time of manure and slurry in the stable before the excretions are removed. This may be illustrated by Canadian observations: a residence time of 1 hour gives NH_3 loss 5% of total N, 1 day a loss of 21% and 1 week a loss of 27% (Beauchamp and Burton, 1985).

- Increasing temperature and high air humidity (above 70%). Thus overcrowding promotes NH_3 emissions.

- Increasing ventilation rate can improve the conditions for the animals but also increase the NH_3 emissions. The NH_3 concentrations in stable air vary greatly, even in the same stable. Concentrations between 0.06 and 39 mg NH_3-N/m^3 (0.1 and 67 ppm) are reported, but the range of approximately 3 to 18 mg NH_3-N/m^3 ppm seems more representative (Fabry *et al*, 1990). Occupational health considerations limits the acceptable maximum concentration to 15 mg NH_3-N/m^3 in most countries.

- Increased exposure of wastes to air during collection and removal. If there is stirring, dripping, etc. enhanced emissions can occur.

The methods for manure storage influence NH_3 emissions. If the manure is stored beneath and in direct contact with the stable, the emissions will add to those generated in the stable itself. If the wastes are stored separately from the stable, covering e.g. with straw or floating plastic pieces reduce emissions, but such measures are most practicable in northern Europe. The warmer climate in southern Europe promotes anaerobic fermentation and gas (methane) formation in closed stores. Liberal addition of straw increase the C/N ratio and can promote NH_3 binding by microbial processes (Kirchmann and Witter, 1989). The emissions also depend on how closely the manure is packed (Isermann, 1990a,b).

Drying of manure involves NH_3 stripping and thus enhanced emissions, unless manure is acidified or is naturally acidic (poultry manure). Details about how emissions depend on stable construction and management have been reviewed (Isermann, 1990a). In practice the emissions from different types of stables are not all that different, annual emissions tend to fall within a range of 4 to 18 kg NH_3-N/livestock unit (a 500 kg cow).

NH_3 emissions from prolonged storage of slurry can be about 10 to 20% of total N. If the slurry is aerated additional NH_3 emissions can occur (Kirchmann and Witter, 1989), concurrent with the nitrification of NH_4^+ to nitrate and further loss of N through denitrification.

Especially large emissions will occur from long time open storage in lagoons or ponds. In such primitive waste treatment systems N is emitted as NH_3 as the free evaporation proceeds. It is therefore not surprising that the results of measured NH_3 emissions vary from country to country, depending on local conditions and traditions in animal husbandry. This is taken into consideration when estimating emission factors and calculating emissions from the various nations in western Europe, as far as published data provides guidance.

In the calculations (spreadsheets at Appendix C), stable and storage emissions are combined. Details are found in the introduction part of Appendix C.

3.2.4 Ammonia Emissions from Application of Animal Manure and Slurry

3.2.4.1 Background

There is general agreement that spreading of manure is a major source of atmosphere NH_3 and also an emission that can be greatly reduced.

Animal wastes are present in 2 forms: as slurry or as farmyard manure (with straw). For simplicity the word "manure" is used for both forms. Application of manure returns plant nutrients to the soil and the organic matter contributes towards the maintenance of adequate amounts of soil organic matter and a soil structure favourable for plant development.

Traditionally manure has been surface spread on pasture and arable land at times convenient to the farmer. The machine used for slurry application is often a vacuum tanker with a nozzle and splash plate.

Some northern European countries have regulated manure use since the early 80's in order to avoid water pollution from surface run-off, e.g. by prohibiting spreading on frozen ground.

Recently new techniques of slurry spreading have become available to reduce problems with odour and loss of NH_3 (Vlassak *et al*, 1991; Voorburg, 1991). Examples are slurry acidification (Stevens *et al*, 1989a, Frost *et al*, 1990, Pain *et al*, 1990) injection systems and irrigation after spreading (Korevaar and den Boer, 1990; Bussink and Bruins, 1992). Band spreading through trailing hoses has also been investigated. This application method reduces the contact area with air, which delays manure drying and thus somewhat reduces vapourisation losses (Morken, 1991). However, measures taken to reduce NH_3 emissions after spreading may increase emissions of N_2O from the soil (Granli and Bøckman, 1994). This topic deserves clarification.

The EEC directive concerning the protection of waters against pollution caused by nitrates from agricultural sources (EEC, 1991) limits manure application to 170 kg N/ha/year (210 kg N/ha/year can be permitted for the initial 4 years of the programme) for land draining to ground or surface water with a nitrate content above or approaching 50 mg NO_3^-/l. This and other measures such as establishment of codes of good agricultural practices should over time influence animal densities and current husbandry practices in some areas, and thus also local NH_3 emissions.

3.2.4.2 Ammonia emissions following manure application

NH_3 emissions after manure application have been reviewed by Sommer (1990b) and by Isermann (1990a) who lists the results of 18 reports. The emissions were typically about 37% of applied NH_4^+-N, but ranged from about 1% (injection of slurry into the soil) to almost 100% (spreading on straw mulch).

The contact time between slurry droplets and air is short, thus only a small part (1-4%) of the NH_3 present in the slurry is lost during the spreading (Sommer, 1989; Pain *et al*, 1989; Jarvis and Pain, 1990). The major part of NH_3 emissions from manure application takes place through slow evaporation from manure left on the soil (or grassland) surface after the spreading.

The emissions increase with increasing temperature and prolonged residence times on the soil surface. Persistent winds may increase loss rate, while rain can reduce emissions (Whitehead and Raistric, 1991; Bussink and Bruins, 1992). Horlacher and Marschner (1990) provide an extensive list of factors influencing NH_3 emissions (Table 7).

Measures undertaken for good reasons can carry unwanted environmental penalties. Thus liming is necessary to maintain soil productivity, but increases NH_3 emissions from soils after manure application (Sommer, 1990b).

Estimates of emissions carry a rather wide margin of error. The dependence on weather conditions implies that the emissions probably vary unpredictably from year to year.

The estimates for emission factors for the various countries are given in Appendix C.

3.2.5 Ammonia Emissions from Grazing Animals

In current agriculture, pasture husbandry is almost exclusively limited to ruminants (cattle, sheep, goats) and horses. Farms practicing alternative (e.g. organic) agriculture put poultry and pigs to pasture too, but less than 1% of Europe's farms practice such systems.

It is common in most countries that at least some of the cattle graze during summertime and in a few countries summer grazing is mandatory. The length of the period that cattle are outside depends on climatic conditions in the specific countries. In summer cattle are often kept in the shed during milking time or during the night. However, in most countries some dairy cattle are stabled all the year, and in some regions almost all dairy cattle are stabled.

Grazing of cattle on fertilised pastures is most common in northern Europe. In southern Europe, (southern France and Italy), dairy cattle are mostly stabled all year, while beef cattle graze natural pastures.

Sheep and goats are put to pasture when weather permits in all countries.

Table 7 Factors Influencing NH_3 Emissions (Isermann, 1990a after Horlacher and Marschner, 1990)

Factors	Low	← NH_3 losses →	High
1. Time	Short (min to 1 h)	↔	Long (several h or d)
2. Manure properties			
a. Flowability	High	↔	Low
b. Content of dry matter[a]	Low	↔	High
c. NH_4^+ content	Low	↔	High
d. Quantity applied	Low (high infiltration)	↔	High (low infiltration)
3. Weather			
a. Sunshine[b]	Low	↔	High
b. Temperature[b]	Low	↔	High
c. Humidity	High	↔	Low
d. Wind speed/profile[b]	Low	↔	High
e. Precipitation[b]			
. Quantity (distrib.)	High	↔	Low/none
. Type	Snow on slurry	↔	Slurry on snow
4. Soil			
a. Infiltration[a]	High	↔	Low
b. CEC (soil type)	High (clay, loam)	↔	Low (sand)
c. pH level	Low	↔	High
d. Buffering capacity	Low	↔	High
e. Harvest residues[a] (grass) stubble + straw	Low (none)	↔	High
f. Vegetation	Present	↔	None
5. Measures (farmer)			
a. Incorporation[a]	Yes	↔	No
b. Dilution[a]	Yes	↔	No
c. Soil preparation	Aerobic	↔	(anaerobic)
d. Additions	Acid	↔	Base

a Direct influence
b Indirect influence

3.2.5.1 Pasture

Herbage production of pastures in western Europe depends on the level of N input. The sward can receive N as fertiliser or manure, but also from legumes, like white clover, present in the sward. Much research, recently reviewed by Simpson and Steele (1983); Frame and Newbould (1986) and Haggar (1989), has been done on grass/clover swards. Under western European conditions white clover in a mixed sward is able to fix on average 160 kg N/ha·year with a good grass-clover ley fixing 100-200 kg N/ha·year. The N intake of a grazing animal on grass/clover swards is comparable to or even higher than on fertilised grass swards. Grass/clover swards perform well on clay and loess soils, but it is difficult to maintain clover in the sward on less fertile e.g. sandy soils. Hence clover swards have been largely supplanted by more productive fertilised grasslands (Simpson and Steele, 1983; Haggar, 1989).

A rich supply of NO_3^- suppresses biological N fixation, and the 2 alternative N supply routes: legumes and fertilisation with mineral fertilisers or substantial amounts of manures, are mutually incompatible. N excretion from animals at pasture is mostly urea and immediately available to the grass as a nutrient source. As a result of this circulation a grazed pasture behaves as if it received a higher input of N than a sward where the grass is harvested and removed.

Intensive grass in the Netherlands given 400 kg N/ha produces about 12-16 t/ha dry matter/season with 3.5% N. If the sward is only grazed, the optimal N application rate is still 400 kg N/ha for clay soils, but on light sandy soils the optimal rate drops to 250 kg N/ha (Deenen, 1990).

In Norway where the growing season is shorter than in the Netherlands, mown grassland given 200 kg N/ha produces about 8 t/ha with 2% N. If the sward is grazed, dry matter production is reduced to 4.5 - 5.5 t/ha, but the N content increases to 3 - 3.5%. The carrying capacity and N circulation with associated emissions from grasslands thus vary substantially. These factors are taken into consideration when are calculated national emissions in Appendix C.

3.2.5.2 Ammonia Emissions from Grazing

In pasture husbandry the NH_3 emissions arise from urination and excreta dropped on the field by the animals or lost on unproductive areas, e.g. roads, manure spreading, the animals breath and flatus, fertiliser use (Section 3.3), decaying vegetation, emissions from plants (Section 3.4).

The amount lost can be extremely variable depending on conditions (Jarvis and Pain, 1990; Bussink, 1992, 1994). The processes leading to gaseous N emissions from grassland are well understood (Garrett, 1991; Jarvis, 1991).

While in droppings (faecal matter) only 10 to 30% of the N is in soluble form, most of the N in urine is soluble, mainly as urea. In the field urea is rapidly (within days) hydrolysed to NH_3 (Vertregt and Rutgers, 1988, Lockyer and Whitehead, 1990; Gilman and Sherwood, 1991; Spatz *et al*, 1992). Urination creates alkaline patches of soil rich in NH_3, this furthers extensive volatilisation (Doak, 1952). Lantinga *et al* (1987), found that in the Netherlands the average N input by urine to the part of a pasture affected by urination was equivalent to about 500 kg N/ha. Urine is regarded as the main source of NH_3 emissions as there is more N voided with urine than with droppings, and much of the N in faeces is bonded in organic matter.

Droppings are distributed patchwise on the field and lose NH_3 at about the same rate as urine patches, but the area covered by faeces is less than 10% of the area affected by urine. The droppings represent an even higher N concentration than the urine patches, but lose NH_3 at a lower rate (Lantinga *et al*, 1987).

Factors that influence NH_3 emissions from the field vary during the day (e.g. temperature, moisture, wind), emissions therefore show marked variations in time. Emissions may also depend on soil type and on the grazing systems e.g. continuous or rotational grazing (Simpson and Steele, 1983; Jarvis, 1990; Bussink, 1992, 1994).

When grassland is heavily fertilised the N content of the herbage increases beyond that which can be utilised in digestion and protein formation in the rumen, and the excess is excreted in urine.

Increased urea concentration in urine enhances NH_3 emissions and reduces the sward's ability to cope with the high N content of the urine patches (Deenen, 1990; Bussink, 1994).

Highly fertilised and productive pasture can carry somewhat more animals/ha than less intensively managed grassland, but the increased productivity is associated with a greatly increased NH_3 loss. Jarvis (1990) refers to UK results with young steers where emissions were 1 kg NH_3-N/animal·[grazing year] for a grass-clover sward, compared to 1.5 and 3.3 for grass given 210 and 420 kg N/ha. Similar results have been reported for other countries (Isermann, 1990a,b).

Nevertheless, it is the balance of N to digestible carbohydrates in the feed that is important. Grazing of sheep on pure clover swards gave even greater NH_3 emissions than those from grass fertilised with 420 kg N/ha (Jarvis, 1990).

Dairy cows on pasture in intensive husbandry are often given supplementary feed (concentrates), 2 to 10 kg/day depending on milk yield. When such feed is rich in protein the N excretion in the urine is further enhanced.

As in the case of stabled animals, N excretion can be reduced if the supplementary feed is given as easily digestible carbohydrates with a low N content, (e.g. cereals), so the total N intake of the animals approximate their actual needs (Isermann 1990b; Van Vuuren and Meijs, 1987). While the intake of N and digestible matter for stabled animals can be managed in detail, similar close control can not be achieved for grazing animals. The emissions from cattle at pasture are thus less easily controlled than in stables. But adjustment of fertilisation rate and provision of supplementary feeds low in protein gives scope for some reduction of NH_3 emissions to a practical minimum, even for animals at pasture.

Field measurements of NH_3 emissions from grazing animals are only available from north-western Europe. Both UK and Netherlands studies indicate that about 8% of excreted N is lost. This is discussed in detail in appendix C. For animals on rough grazing with low N intake the potential for NH_3 vaporisation may be lower, but at least for southern Europe the higher temperature may compensate for this.

These emissions do not include emissions due to manure application on pastures. Where all stable manure is spread on the pasture about half of the emissions from a cattle heard comes from the pasture in the grazing season due to the grazing, the rest mainly from manure application with small amounts coming from decaying plants, and fertiliser use (Isermann, 1990a).

3.3 AMMONIA EMISSIONS FROM APPLICATION OF MINERAL FERTILISERS

3.3.1 The Origin of Ammonia Emissions from Fertiliser Application

In contrast to animal manure, fertilisers as such do not give off NH_3 when exposed to air. They are stable, solid components, with anhydrous NH_3 and urea-ammonium nitrate (UAN) solutions as the exceptions. Most fertilisers except anhydrous ammonia, diammonium phosphate and urea give acidic solutions when dissolved in water (Table 8).

When the fertiliser particles initially dissolve the concentration of NH_4^+ will be high, with potential for NH_3 emissions. As the solution is diluted and spreads into soil pores and on soil particles, reactions will occur, and the pH of the solution will gradually approximate that of the soil solution, but for most fertilisers the approach to the new pH value will be from the acidic side of the pH scale (Whitehead and Raistrick, 1990).

Table 8 pH of 1% of Solutions of Fertilisers in Water (Bøckman, 1991)

Diammonium phosphate	7.9
Urea	7.6
Ammonium nitrate	5.1
Mono ammonium phosphate	4.4
Complex fertilisers	5.2 (4.7-6.6)[a]

a Typical value and range

NH_3 emission following fertiliser application results from chemical reactions with soil components after the fertiliser has been applied and dissolved in soil water, rain or dew. These reactions have been reviewed by Terman (1979); Fenn and Hossner (1985); and Bock and Kissel (1988). The main features of these reactions are discussed in Appendix C.

NH_3 emissions from applied fertilisers come only from N in NH_4^+ form, or from compounds such as urea that can give NH_4^+ through reactions with soil constituents. Fertiliser N in the form of NO_3^- does not give rise to NH_4^+ emissions. Application rates are given as total N. For some important types of fertilisers (NP, NPK) the portion of the N in NH_4^+ form varies with grade and production process.

Soils differ in their reactivity and in their ability to provide conditions (e.g. high pH) conducive for NH_3 emissions. Emissions tend to be higher from calcareous soils than from more acid soil types, notably after application of ammonium sulphate, as discussed in appendix C.

3.3.2 Fertiliser Usage in Europe

The global application of N fertiliser in 1989/1990 was about 79 Mt N/year, of which 38% was urea (IFA, 1992). The N application in western Europe was 9.6 Mt N/year. Details about national fertiliser use are given in the spreadsheets in Appendix C.

The European traditions in fertiliser use differ from those of the rest of the world in that the main types used are ammonium nitrates (straight ammonium nitrate and calcium ammonium nitrate i.e. ammonium nitrate mixed with about 20 - 25% calcium carbonate or dolomite).

Urea accounted only for 18% of the N application in western Europe in 1989/90. Nevertheless, about half of the NH_3 emissions from fertiliser application in western Europe derives from urea. Urea is thus the largest single source of fertiliser derived atmospheric NH_3, although this only contributes about 4% of the anthropogenic NH_3 emissions in western Europe. The use of urea increased about 40% between 1984 and 1989, notably in France, Germany, Spain and the UK. There was some reduction in its application in Italy when about 40% of the N is applied as urea. In some countries (the Nordic countries, the Netherlands) urea is hardly used (IFA, 1992).

Ammonium sulphate accounts for only a small part of the fertiliser supply (less than 3%). European agricultural soils now require increasing amounts of sulphur as the "free contribution" of atmospheric sulphur compounds from air pollution is diminishing, and ammonium sulphate may be more used in the future, even though it is rather expensive.

Despite the increasing use of urea and its dominant use in some regions (Italy), most of the fertilisers applied in Europe as a whole are not of the types principally associated with high levels of NH_3 emissions.

Both arable land and grassland are fertilised. The pattern of fertiliser use in western Europe is given in Table 9.

This only refers to fertiliser N application. Some crops, notably fodder crops and grassland, also get animal manure in amounts that may exceed the fertiliser N application.

Fertiliser N application on arable land varies with crop, soil and location. It is usually within the range of 70-250 kg N/ha. In the south of Europe grain maize receives the highest applications, but covers only 0.4 Mha. In the north oil seed rape, potatoes, sugar beet and vegetables are usually the crops that receive most fertiliser N/ha, while pulses are given little or no N. N application to fruits and wine is low, usually within the range of 30-70 kg N/ha.

In some regions (e.g., the Netherlands) permanent grassland under intensive management is given the largest mineral fertiliser applications of all crops, but this is not representative for Europe as a whole.

Table 9 Fertiliser Usage and Fertilised Areas in Western Europe in 1990 (FAO/IFA/IFDC, 1992)

	Fertiliser N application (Mt N/y)	% of N applied	Fertilised area (Mha)
Cereals, including grain maize	4.9	47	39.7
Fertilised grassland, fodder crops	3.5	34	40.8
Others, including permanent crops such as fruit, wine	2.0	19	25.2

3.3.3 Emission and Emission Factors

Various sets of emission factors are in use, they are listed in Table 6. They differ in detail. A detailed discussion on this topic is presented in Appendix C. The discussion here is limited to the main principles and results.

Some fertiliser is applied at seeding as a band below seeding depth. The NH_3 emission potential from this fertiliser will be low. Nevertheless most is applied on the surface, and all N applied as top dressing or on grassland is so applied. Surface or near surface application is assumed in the discussion of emission factors.

The emissions of NH_3 from application of urea have been studied extensively, they are generally in the range of 10 to 25%.

The knowledge of emissions from other fertilisers is more sparse. The main conclusion is that such emissions are markedly lower (less than 10%) than those of urea, with the possible exception of ammonium sulphate and diammonium phosphate on calcareous or otherwise alkaline soils, and anhydrous ammonia injected under improper conditions. Details about emission factors from fertiliser use are given in Appendix C, cf NH_3 volatilisation.

Because of the marked influence of soil properties on the potential for NH_3 emissions from applied fertilisers, different factors are used for each country depending on the range of pH recommended as good practice, and on the occurrence of calcareous soils. Details are given in Appendix C.

Table 10 Emission Factors from Fertiliser Application (% of N content) Used in Other Emission Estimates

	Asman, 1992[a]	Buijsman *et al*, 1986[a]	Whitehead and Raistrich, 1990[b]		Flieg *et al*, 1939[d]	Amberger, 1990 Knueppel, 1988[d]	SCB, 1991[e]
			Grassland	Arable[c]			
Ammonium sulphate	8	15	9.9	7	3.0	5-10	2
Ammonium nitrate	2	10	2.5	1.8	-	-	2
Calcium ammonium nitrate	2	2	-	-	1.4	1-5	2
Ammonia	1	10	-	-	-	-	25
Urea	15	10	16.5	11.6	6.0	10	25
Diammonium phosphate	-	5	4.9	3.4	-	1-3	2
Monoammonium phosphate	4	5	1.5	1.1	-	-	2
Complex fertilisers	2.5-4	1	-	-	0.02	1-5	2
Calcium cyanamid	-	-	-	-	3.3	-	-

a Assumed to be general for Europe
b For UK conditions
c Assumed by authors to be 30% lower than emissions from grass as subtantial amounts are drilled rather than spread on the surface
d Cited by Isermann, 1990a
e For Swedish conditions

3.4 AMMONIA EMISSION FROM PLANTS

The main contact area between air and land surface is vegetation. It has long been known that plants can both emit and take up NH_3 from air, this topic is reviewed by Farquhar *et al* (1983); Sutton (1990); Schjørring (1991); Raven *et al* (1992); Sutton *et al* (1993) and Holtan-Hartwig and Bøckman (1994).

Plants have a compensation point for NH_3 concentrations in air, a concentration where NH_3 is neither emitted nor taken up. At atmospheric concentrations below this level plants will emit and at concentrations above take up NH_3 through the leaves.

Farquhar *et al* (1980) found a compensation point for young plants (20-40 day) of about 2-5 μg NH_3 N/m^3, or about the normal concentration of NH_3 in air in agricultural areas. Parton *et al* (1988) found a somewhat higher value for wheat (15 μg NH_3-N/m^3). Morgan and Parton (1989) reports that the compensation point for wheat increases as plants approaches maturity, from about 13 μg NH_3-N/m^3 at early to 23 μg NH_3-N/m^3 at late grain filling.

This higher range (13-23 μg NH_3-N/m^3) for the compensation point is somewhat above the usual NH_3 concentration in rural atmosphere, and should indicate that these crops generally emitted rather than took up NH_3. However, the measurements are too few for generalised statements.

In contrast Langford and Fehsenfeld (1992) report a compensation point as low as 0.5 μg NH_3 N/m^3 for a N-limited Colorado forest.

A small amount of NH_3 emitted from soil or manure beneath a crop can be taken up by the leaves, but most will escape from the crop canopy to the atmosphere (Sommer *et al*, 1993).

Uptake and emission of NH_3 vary, and plants may act both as a net sink for atmospheric NH_3 during part of their development and as a net source for other periods (Sutton, 1990). There are also diurnal and short term variations, as the metabolic state differs between day and night with the stomata closed during night and open during the day, hence nocturnal exchange of NH_3 between leaves and atmosphere is greatly restricted. Also the compensation point changes with temperature. This complicates evaluations of NH_3 emissions from plants.

The main period of net emission is probably during ripening when N is mobilised and transferred as organic compounds to the grain. Emissions of 1.3 kg NH_3-N/ha from well fertilised (160 kg N/ha)

ripening barely giving high yields have been estimated in field experiments in Denmark (Schjørring, 1991). There is evidence that larger losses can occur if ripening is affected by adverse weather (e.g. overcast and low temperature during grain filling period), giving low harvests (Schjørring *et al*, 1989).

Abnormally low spring barley harvests (less than 92% of normal) occurred in Denmark 7 times during the period 1950-90. Some of these failures were due to adverse early spring and summer conditions (drought). A rough estimate of the frequency of adverse weather conditions in the late summer in this area that could be associated with especially high N emissions as found by Schjørring *et al* (1989) is approximately once in 10 years.

Schjørring *et al* (1989), present data indicating that the potential for N emissions from crops increases with increasing N fertilisation level. The emissions may also be increased by plant diseases, such as fungal attacks (Jenkyn and Finney, 1984). More field measurements addressing these issues are needed before such effects can be taken into account in estimating of NH_3 emissions from agriculture.

It can be noted that measured wet depositions in Denmark (Grundahl and Groenbeck-Hansen, 1991) show only small variations throughout the year including summer and early autumn (the grain filling period). The maximum is in spring and early summer with some evidence for an increase in late autumn, corresponding to times for manure spreading (Andersen, 1990). This indicates that emissions from ripening cereals do not provide a major input to those depositions.

Published data for NH_3 emissions from crop plants present an incoherent picture. Measurements with micrometeorological techniques seem to give the most direct and reliable indications of field emissions (Holtan-Hartwig and Bøckman 1994). The results of Schjørring and Byskov-Nielsen (1990); Sutton (1990) and Schjørring (1991) indicate net emissions of about 1 kg N/ha/year (with a range of 0.5-1.5) from cereals. This value has been used in Denmark for the purpose of loss calculations (Dyhr-Nielsen *et al*, 1991). In contrast, results by Harrison *et al* (1989) can be taken to indicate a crop emission of 9.8 kg NH_3-N/ha/year in southern UK (Sutton, 1990).

It seems that NH_3 emissions from plants are subject to a variety of influences and that measurements must be extended over a series of years in order to obtain a realistic picture.

As more data from micrometeorological studies are published the situation should be clarified. Presently field data are only available for cereals, but it is probable that other crops also show similar emissions (Holtan-Hartwig and Bøckman, 1994).

Decaying vegetation gives off NH_3, especially if it is rich in N (Whitehead *et al*, 1988), e.g. legume-based green manure (Janzen and McGinn, 1991). Vertregt and Rutgers (1988) estimated this loss from grazed fertilised pasture to be 3 kg N/ha over 180 days. For the UK this loss is estimated to be 10 kt NH_3-N/year, from the 7.2 Mha lowland grassland, or 1.4 kg NH_3 N/ha/year (Whitehead and Lockyer 1989).

Holtan-Hartwig and Bøckman (1994) lists published measurements of NH_3 emissions from plants. They conclude that 1.5 kg NH_3-N/ha/year more than the loss would have been from natural vegetation is an appropriate calculation factor. Areas and calculated emissions are given in the speadsheets, Appendix C.

NH_3 emissions from plants represent an incompletely researched factor. If a higher value of 6 kg NH_3/ha for crops on arable land and 1.5 N/ha for managed pasture is used as calculation factors, the emission could be approximately 0.5 Mt NH_3-N/year or about 11 % of the anthropogenic emissions. This must be regarded as an extreme value, since emissions as high as 6 kg NH_3-N/ha are only expected under adverse weather conditions during crop ripening.

However, the calculation indicates that NH_3 loss from crops is only a minor source of atmospheric NH_3 even conditions favourable for high emission levels.

3.5 OTHER ANTHROPOGENIC SOURCES

3.5.1 Ammonia from Use of Explosives

Ammonium nitrate used in explosives is the largest single market for NH_4^+ containing compounds outside agriculture. Approximately 0.1 Mt ammonium nitrate-N/year is used annually in western Europe. Some NH_3 is liberated on detonation of ammonium nitrate based explosives. The amounts vary with conditions, but according to manufacturers' estimates they are less than 1% of the N (Nygaard, 1993). Hence NH_3 emission from this source is less than 1 kt NH_3-N/year in western Europe. This is included in our estimate of "miscellaneous anthropogenic emissions".

3.5.2 Industrial Domestic and Various Minor Agricultural Sources

NH_3 is used as a raw material in diverse chemical processes, e.g. production of polyamides and some other plastics, of some surfactants (fatty amines) and pharmaceuticals. NH_4^+ containing salts are also used as N source in some industrial fermentations. The tonnage is small compared with fertiliser production, and the emissions to air are subject to regulation and control. The emissions for whole of Europe should thus be considerably less than that from the fertiliser industry, at most a few kt/year.

Slightly more may come from the use of NH_3 in refrigerators and for production of aqueous NH_3 for household cleaning. In Scandinavia (Denmark, Norway and Sweden) these markets take about 1.1 and 5.4 kt NH_3-N/year respectively. Much of this will end up in the sewer, only a part (unknown) is emitted to the atmosphere.

A recent Swedish study (SCB, 1991a) considered these and other small anthropogenic sources of atmospheric NH_3 (Table 11).

Table 11 Small Anthropogenic Sources of Atmospheric NH_3 in Sweden (SCB, 1991a)

Source	Emission (t NH_3-N/y)
Refrigeration, household chemicals and minor industrial sources	660
Households without sewer access	330
Pets (cats and dogs)	410
Gardens	200
Total	1,600

Emissions from agricultural sources were estimated at 42,800 t NH_3-N/year, hence these minor (mainly urban) emissions should represent about 4% of agricultural emissions. Asman (1990) used 4% for estimating such emissions in Denmark.

Laidig (1990) discussed emissions in Germany from refrigeration, reduction of NO_x in power stations, transport and tobacco use; these sources combined are 1 or at most 2% of agricultural sources.

Man emits NH_3 through expired air. Two studies reported that human expired air has NH_3 levels between 105 and 2,219 $\mu g/m^3$ and between 196 and 1,162 $\mu g/m^3$ during mouth breathing (IPCS, 1986). A major source is believed to be the oral microflora. Assuming the extreme case of 2 mg NH_3-N/m^3 in 20 m^3 exhaled air/day, the 372 million western Europeans at most exhale about 5,400 t NH_3-N/year, and probably considerably less. This is insignificant compared to other emissions and is not listed as a separate item, but included in the estimate of various minor sources mentioned below. However, Atkins and Lee (1993) give estimates of human emission rates ranging from 0.21-1.3 kg NH_3-N/year; person and Klaassen (1992b) suggests 0.25 kg NH_3-N/person·year as an appropriate factor. This would imply that human beings and their waste emits some 0.1-0.5 Mt NH_3-N/year, or about 2 to 10% of total emissions. At least the upper limit seems unreasonably high, as most human excretions end up as water pollution. However, Atkins and Lee (1993) also make the reservation that their estimate could be an order of magnitude too high. Sewage contains 12 g N/person·day or about 4.4 kg N/person·year, or in western Europe approximately 1.5 Mt N/year. It seems unlikely that a large percentage of this ends up as atmospheric emissions. Sewage is diluted by water in urban areas, and further diluted by drainage. NH_3 is not regarded as a significant air pollutant from waste water treatment plants. Sewage sludge is comparable to solid manure in N content and application of sludge should cause emission of NH_3. Beauchamp *et al* (1978) reported atmospheric NH_3 concentrations up to 2.4 mg NH_3-N/m^3 after sludge application. This contribution to atmospheric NH_3 can not be quantified at present due to lack of data but it may add a further 1 or 2 percent of total emissions. The contribution from urban areas to NH_3 emission remains incompletely researched.

Burning of biomass and fossil fuel (especially coal) also gives off some NH_3. This was discussed by Fabry *et al* (1990) for Europe. They estimate these emissions to be 1-2% of those from agriculture. Kruse *et al* (1989) also point to these various sources as emitters of NH_3, but without firm numerical conclusions as to their importance, due to lack of data.

There are also some minor animal sources not covered in the main listing of animals in agriculture: large birds (e.g. turkey, goose), domesticated "wild" animals (deer), fur animals. They can be significant NH_3 sources in some localised areas, but on the large scale their contribution will be small. There must also be emissions originating with household pets but statistics and studies that can be used as a basis for estimates are lacking. Such contributions should also be considered when "miscellaneous emissions" are estimated.

The data basis for estimating miscellaneous emissions of NH_3 is weak. The considerations listed above indicate that such emissions probably are less than 10% of total emissions and more than 4

or 5%. Hence 8% of total emissions is used as an estimate of "miscellaneous anthropogenic emissions".

3.6 ANTHROPOGENIC AMMONIA EMISSIONS IN WESTERN EUROPE

Based on the material presented above and given in more detail in Appendix B and C, the emissions of NH_3 to the atmosphere in western Europe in 1990 are shown in Table 12.

Table 12 Anthropogenic Ammonia Emissions in 1990

	From animals and their waste (kt NH3-N)								
	Stables[a] (kt)	Surface spreading (kt)	Grazing (kt)	Total (kt)	Fertiliser application (kt)	Industry (kt)	Crops (kt)	Miscella-neous (kt)	Total emissions (kt)
Austria	30	28	4	62	1.6	0.4	5.3	6.1	76
Belgium/Luxembourg	29	61	8	99	4.2	1.1	2.3	9.2	115
Denmark	31	62	5	97	7.5	0.4	4.2	9.5	119
Finland	9	25	2	36	2.7	0.7	3.9	3.8	47
France	285	216	63	564	127.6	2.0	46.1	64.3	804
Germany	245	212	46	504	78.4	1.5	27.1	53.1	664
Greece	25	18	14	57	18.6	0.5	13.8	7.8	98
Ireland	44	55	25	124	12.5	0.8	8.5	12.6	158
Italy	251	131	9	390	64.0	3.3	21.0	41.6	520
Netherlands	60	124	16	200	8.5	3.6	3.0	18.7	234
Norway	8	22	2	32	1.1	0.9	1.5	3.1	39
Portugal	34	18	7	59	6.2	0.3	6.8	6.3	78
Spain	157	77	36	270	96.1	1.8	45.8	36.0	449
Sweden	14	36	3	54	2.2	0.3	5.1	5.4	67
Switzerland	28	17	2	48	3.4	0.0	3.0	4.7	59
United Kingdom	136	161	69	366	55.9	1.4	26.9	39.1	489
TOTALS	1,387	1,264	310	2,961	490	19	224	321	4,016
% of total NH_3-N emissions	34.5	31.5	7.7	73.7	12.2	0.5	5.6	8	100

a Including emissions from manure storage

SECTION 4. DISCUSSION

4.1 THE ECETOC ESTIMATE COMPARED WITH OTHER ESTIMATES

The ECETOC task force estimate of anthropogenic NH_3 emissions in western Europe is somewhat higher than other regional estimates but the ranges of uncertainty of the estimates overlap (Table 13). A more detailed comparison is given in Table 14. In constructing Table 13 and 14 the original estimate of Buijsman *et al* (1986) is increased with 20% (as discussed in Section 1.3), and emissions given as NH_3 are converted to NH_3-N.

Table 13 Comparison of NH_3 Emissions in Western Europe (Mt NH_3-N/y)

	Best estimate	Range (± 30%)
Buijsman *et al* (1986) (corrected value)	3.1	2.2-4.2
Asman (1992)	3.2	2.2-4.2
Sandnes and Styve (1992)	3.1	2.2-4.2
ECETOC	4.0	2.8-5.2

The difference between the other estimates and that of ECETOC is mainly because:

- Calculation of emissions from animal husbandry using national N excretions as basis has led to an average of 8 % higher emission estimates than those of Asman (1992). In view of the uncertainties inherent in the estimate this difference appears to be minor. Möller and Schieferdecker (1989) argued that published estimates tended to be low.

- The estimates of NH_3 emissions from fertiliser production used in other estimates are generally too high as discussed in Chapter 2. However, in all estimates the contribution of fertiliser production to atmospheric NH_3 was very small, so a correction of this item has insignificant impact on the total.

- The ECETOC estimate includes emissions from crops and also makes allowance for miscellaneous anthropogenic emissions, both items usually not included in other estimates. They account for 14 % of the ECETOC estimate and explain the remainder of the difference between this estimate and that of e.g. Asman (1992).

Table 14 Comparison of NH_3 Emissions per Country (kt NH_3-N)

	ECETOC		Asman, 1992		Buijsman *et al*, 1986		Sandnes and Styve, 1992	Klaassen, 1992
Reference year:	1990		1989		1982		1989-91	1986
Sector:	Animal	Total	Animal	Total	Animal	Total	Total	Total
Austria	62	76	69	73	62	72	70	65
Belgium-Luxembourg	99	115	90	95	78	87	95	90
Denmark	97	119	86	97	87	111	107	84
Finland	36	47	34	42	38	44	35	40
France	564	804	534	636	569	709	635	533
Germany	504	664	576	686	488	578	548	633
Greece	57	98	52	65	69	95	64	82
Ireland	124	158	121	138	110	117	138	105
Italy	390	520	261	339	252	361	337	300
Netherlands	200	234	172	183	128	150	204	196
Norway	32	39	25	29	27	36	25	38
Portugal	59	78	52	58	38	47	58	53
Spain	270	449	220	284	177	232	281	260
Sweden	54	67	45	52	46	52	51	48
Switzerland	48	59	46	50	49	53	50	49
UK	366	489	330	385	307	405	384	403
TOTAL	2,961	4,016	2,713	3,212	2,525	3,149	3,082	2,979

- The emission ascribed to fertiliser application (0.49 Mt NH_3-N/year) is almost identical to that calculated by Asman (1992): 0.500 Mt NH_3-N/year, though a more differentiated set of emission factors is used in the present report as described in Appendix C. The emissions from fertiliser application estimated by Buijsman *et al* (1987) when corrected are slightly different (0.554 Mt NH_3-N/year), the fertiliser consumption in the early 80's was lower than in 1990 but some emission factors used were unreasonably high. Emission factors are discussed in Section 3.3.1 and in Appendix C.

Inspection of Table 14 indicates regional trends in the difference between the ECETOC task force estimate and the others. The difference is most noticeable for the Mediterranean countries: Greece, Italy and Spain, also for France and to some extent for the UK. This reflects the approach of using emission factors adjusted to national conditions rather than standard emission factors for all of Europe, and also the inclusion of crop emissions from the large cultivated areas in these countries.

There are substantial uncertainties with the estimate. These are discussed in detail in Appendix C (Section C.20). The Dutch estimate is probably the best, as agricultural practices tend to be fairly standardised, and more studies have been made on ammonia emissions than in other nations. Even so the Dutch estimate is no better than within the range of ± 30%. The range of uncertainty is probably even larger for countries where few or no emission studies have been undertaken.

At present many assumptions have to be made in preparing the emission estimates. It should be possible to improve the emission estimates by organising regional collection of statistical data on actual practices on animal and manure management throughout Europe, according to a protocol based on the spreadsheet construction and discussion in Appendix C. This could provide suitable tasks for student theses at regional agricultural schools, but the organisation of such a survey was beyond the task force remit.

4.1.1 National Emission Estimates

Some national emission estimates have been published.

Sweden

Statistics Sweden (SCB, 1991a) published an estimate of NH_3 emissions in Sweden in 1988. The estimate was based on interviews with farmers about their use and management of manure, slurry and fertiliser; the calculation method based on loss percentages of N excretions was similar to ours

(Appendix C), though with somewhat different emission factors. The results can be compared with the ECETOC estimate.

Table 15 NH_3 Emissions in Sweden (kt NH_3-N/y)

	In 1988 (SCB, 1991a)[a]	In 1990 (ECETOC)
Animals Stables		
manure	25.1	14
Storage	9.5	36
Manure spreading	4.2	3
Grazing		
Subtotal	38.8	54
Fertiliser application	3.9	2
Crops	-	5
Miscellaneous	2.1	5
Total	44.8	67

a Accuracy ± 20 to 50%

There are considerable differences between these estimates in the subtotals within the animal sector, but otherwise they reflect the trend discussed above; the estimates are comparable within the broad confidence limits but the ECETOC estimate is 50% higher than that of Statistics Sweden.

Denmark

Asman (1990) estimated NH_3 emissions in Denmark in 1988 (Table 16).

The estimates for NH_3 emissions from the animal husbandry sector are similar. Asman's (1990) estimate of emission from fertiliser application is based on the emission factors of Buijsman *et al* (1986). Asman (1992) later revised these emission factors, the emission calculated using the revised factors are given in brackets. Other sources in the estimate of Asman (1990) are restricted to pets, farmed deer and fur animals and human exhalations; industrial sources and crops are not included. The correspondence between the estimates seems satisfactory, when these comments are taken into consideration.

Table 16 NH_3 Emissions in Denmark (kt NH_3-N/y)

Reference year:	1988[a]	1990 (ECETOC)
Animals	95	97
Fertiliser application	23 (13)[b]	7.5
Other sources	4	14.1
Total	122 (112)[b]	119

a Asman, 1990
b As revised by Asman, 1992

United Kingdom

Ryden *et al* (1987) estimated emissions in the early 80s from UK animal sector as 355 kt NH_3-N/year, including emissions from N applied to grassland, but excluding emissions from fertiliser applied to arable land. Kruse *et al* (1989) arrived at a similar estimate of 360 kt NH_3-N/year for the animal sector alone (excluding fertiliser application and also excluding Northern Ireland, for the year 1981). This compares well with the ECETOC estimates of 366 kt NH_3-N/year for the animal sector for the whole of UK, and also with the estimate of Asman (1992) of 330 kt NH_3-N/year. Eggleston (1992) estimated emissions from farm animals as 287 kt NH_3-N/year for the year 1988. In contrast Jarvis and Pain (1990) estimated UK emissions from the animal sector to 177 kt NH_3-N/year. The difference reflects the uncertainties in estimating NH_3 emissions. The review: "N in UK Grassland Agriculture" by Whitehead *et al* (1986) serves to illustrate the complexities of the system and the difficulties in making emission estimates. The impression left when published studies are compared is that the estimate of Jarvis and Pain (1990) is too low.

The estimates for NH_3 emission following fertiliser application were 9.1 kt NH_3-N/year (Jarvis and Pain, 1990) and 12.3 kt NH_3-N/year (Kruse *et al*, 1989, for England and Wales only). The ECETOC estimate is higher: 55.9 kt NH_3-N/year, while Asman (1992) estimated this emission to 67.3 kt NH_3-N/year. Eggleston (1992) used the old emission factors of Buijsman *et al* (1986) to make an estimate of fertiliser-derived NH_3 emission of 95 kt NH_3-N in the year 1988. The factors of Buijsman *et al* (1986) are known to be inaccurate and generally give too high estimates. This topic is discussed in Appendix C (Section 2.6).

Further, the estimate of Ryden *et al* (1987); Kruse *et al* (1989) and Jarvis and Pain (1990) does not include emissions from industry, crops and miscellaneous sources. This explains why the ECETOC estimate of NH_3 emissions in the UK of 489 kt NH_3-N/year is considerably higher than these other

estimates. Eggleston (1992) estimated total UK emissions as about 450 kt NH_3-N/year. This includes numerous minor (miscellaneous) sources.

The Netherlands

In an inventory (VROM, 1987) it was estimated that the total NH_3 emissions (crop emissions are excluded) in 1986, was 212.5 kt NH_3/year with 191.7 kt NH_3-N/year coming from animal husbandry. In a more recent study the emissions from animal husbandry were estimated at 161.7 kt for the year 1991 (TNO and Heidemij, 1993), whereas this is 200 kt in the ECETOC study for the year 1990. Part of this difference may be attributed to the somewhat lower animal numbers in 1991. The year 1991 was also the introduction in practice of new slurry application techniques low in NH_3 emission. In view of this the difference between the estimates is not remarkable.

Table 17 NH_3 Emissions in the Netherlands (kt NH_3-N/y)

Reference year:	1986[a]	1991[b]	1990 (ECETOC)
Shed + storage emissions	68.1	70.0	60
Slurry application	97.8	74.8	124
Grazing	25.9	16.9	16
Subtotal	191.7	161.7	200
Fertiliser	7.8		8.5
Industry	5.4		3.6
Crops	-		3.0
Miscellaneous	7.7		18.7
Total	212.5		234.0

a VROM, 1987
b TNO and Heidemij, 1993

Germany

Isermann (1993b) estimated German emissions in 1991/92: compared in Table 18 with corresponding estimates by ECETOC for 1990.

Table 18 Ammonia Emissions in Germany (kt NH_3-N/y)

Reference year:	1991/92[a]	1990 (ECETOC)
Agriculture - animal sector	541.0	504
- fertiliser application	64.3	78.4
Fertiliser production	1.5	1.5
Miscellaneous	26.8	53.1
Total	633.6	637.0

a Isermann, 1993b

The estimate of Isermann (1993b) for the animal sector was based on an annual average emission of 36 kg NH_3-N/large animal unit (GV). Large animal units (German: GV) are calculated according to a set national formula including all farm animals and 1 GV corresponds to 1 dairy cow with a defined milk production.

The difference between the estimates is not remarkable, and the estimate of total emissions similar. However, the emissions from the animal sector in the 2 estimates are not strictly comparable as they refer to different years, and the number of animals was markedly reduced in Germany around 1990 as a result of changes in German agriculture following reunification. Isermann (1993b) estimated that the emissions from animals in Germany (including eastern parts) in 1988/89 were as high as 695 kt NH_3-N/year.

However, Möller (1992) estimated the NH_3 emissions from farm animals in the eastern parts of Germany in 1988 to 213 kt NH_3-N, and Fabry (1992) arrived at 237 kt NH_3-N as the emission in western Germany. Their total estimate for Germany thus was 450 kt NH_3-N.

The difference between this total and the ECETOC estimate for emissions from the animals and their wastes is about 10%.

Finland

Finish agriculture is somewhat special in that fur animals represent a significant source of NH_3 emissions, as can be seen from the estimate of Pipatti (1992):

While the two estimates differ in detail the differences are not remarkable.

Table 19 Ammonia Emissions in Finland (kt NH_3-N/y)

Reference year	1985/86[a]	1990 (ECETOC)
Cattle	23.1	26.9
Pigs	3.6	6.0
Poultry	1.2	2.3
Fur farms	3.2	-
Fertiliser	3.0	2.7
Industry	1.0	0.7
Total	35.1	38.6

a Pipatti, 1992

4.2 EUROPEAN ATMOSPHERIC BUDGETS FOR NH_3

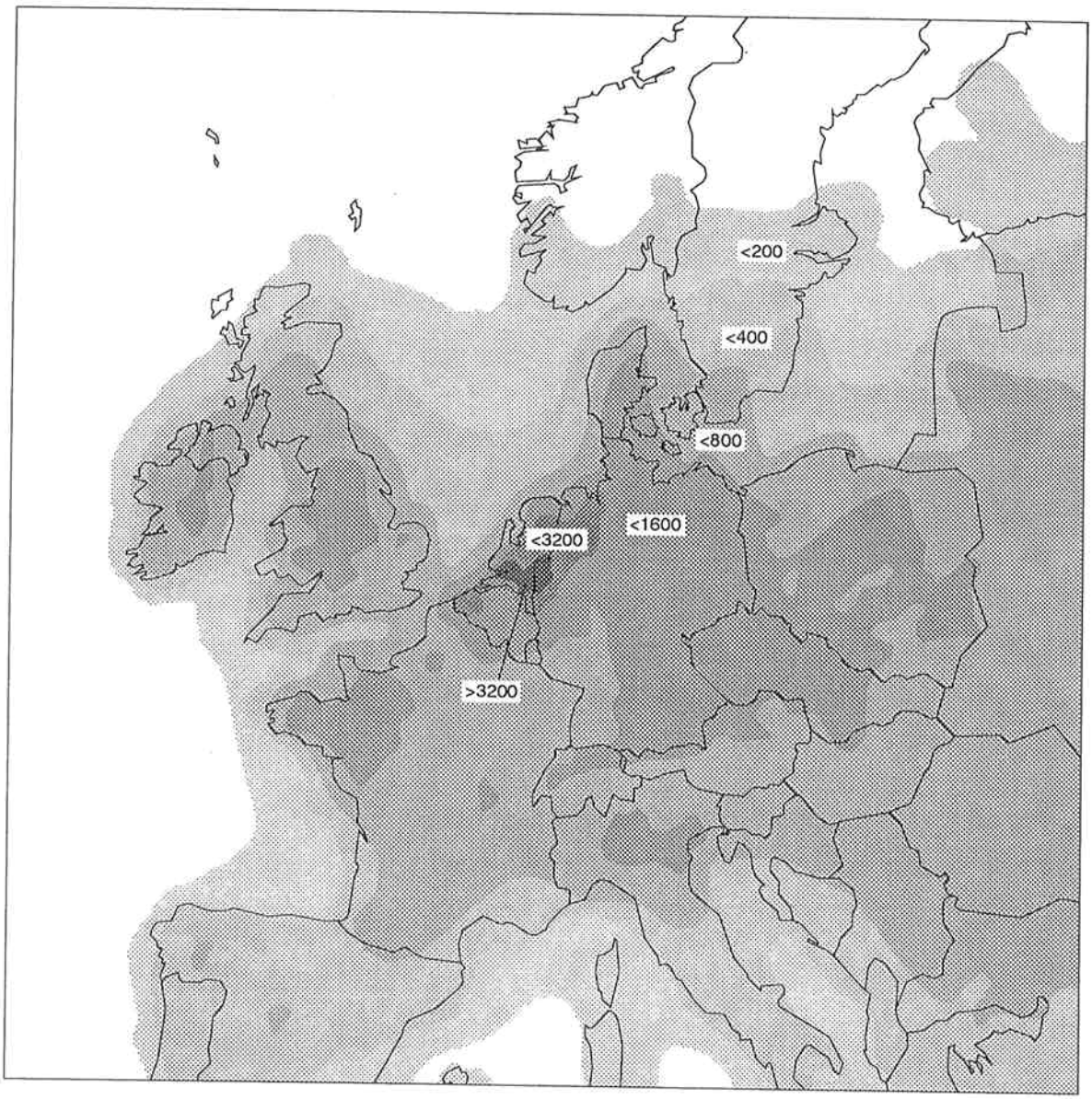
Estimates of NH_3 emissions are used in the EMEP calculated budgets for acidifying components in Europe. The ECETOC results compared with those used by EMEP (Table 14) indicate that the NH_3 emission data currently used in their model in many cases somewhat underestimate the probable emissions as estimated by us.

What goes up must eventually come down, with precipitation or as dry deposition. Figure 6 (from Asman and Van Jaarsveld, 1990) describes the present situation for NH_3 and NH_4^+ deposition in Europe, with the marked concentration of animal husbandry in some areas but also the wide spread occurrence of (presumably) elevated deposition rates.

NH_3 released at ground level diffuses up into the atmosphere in competition with downward deposition on the surface. As NH_3 penetrates upwards it is transformed to NH_4^+ by reactions with sulphuric and nitric acids formed by photochemical processes. Direct oxidation of NH_3 and NH_4^+ is in most instances too slow to remove significant parts of the emitted NH_3 (Logan, 1983; Warneck, 1988). Adema *et al* (1990) suggest that oxidation to N_2O can occur, but this requires confirmation and quantification. A fraction of the NH_3 may penetrate upwards into clouds, where it is readily soluble and can play a role in cloud chemistry by increasing cloud pH.

Whereas NH_3 and NH_4^+ concentrations near ground level are often comparable (Sutton 1990), the NH_3 concentration tends to decrease quite markedly with height. Nearly half (44%) of the emitted

Figure 6 **Calculated Total Deposition of NH_3 and NH_4^+ in Europe** (mol/ha/y) (Asman and Van Jaarsveld, 1990)



NH_3 is dry deposited as NH_3 close to the source (Asman and Van Jaarsveld, 1992). The NH_4^+ is in aerosol form and is less readily deposited until it is washed out, e.g. with rain. Thus the conversion of the NH_3 to NH_4^+ results in long-range spreading of the emissions on a trans-European scale, together with SO_4^{2-} and NO_3^-.

A more detailed discussion on reactions of ammonia in the atmosphere and the problems with measurements of depositions can be found in Sutton *et al*, 1993.

Thus Möller and Schieferdecker (1989) estimated that at least a third of the NH_3 emitted in the former GDR was "exported" to other countries. In Denmark the "import" is 15 kt N/year, the emissions 118 kt and the "export" 74 kt (Dyhr-Nielsen *et al*, 1991). Though the Netherlands is a net "exporter" of atmospheric NH_3 and NH_4^+ (mainly to Germany) for the country as a whole, 22% of the deposition is "import" (Asman and Van Jaarsveld, 1990). Also in the Mediterranean long-range transport of NH_4^+ and NH_3 is an important factor for the atmospheric deposition of N nutrients (Loÿe-Pilot *et al*, 1990).

In principle, measurements of deposition together with appropriate models of atmospheric transport and removal, should provide an independent check on the estimates of emissions. However, the assessment of dry deposition of NH_3 is complicated, and results of modelling studies are not yet conclusive. The studies of Asman (Asman, 1987, 1990; Asman and Van Jaarsveld, 1990; Isaksen *et al*, 1991; Sandnes and Styve, 1992), indicate that the estimates of emissions are essentially correct. Progress in modeling work is impeded by the wide range of uncertainty in emission estimates, incomplete insight in NH_3 exchange processes between atmosphere and vegetation, and the difficulties inherent in diurnal variations in emissions and depositions.

4.3 FUTURE NH_3 EMISSIONS IN WESTERN EUROPE

There are no EEC regulations specifically for NH_3 emissions.

Nevertheless, there are national regulations e.g. Dutch and Danish regulations requiring rapid incorporation of manures into soil. The Dutch target is a 70% reduction in NH_3 emissions by the year 2000, compared with the emissions in 1980. In the UK, guidelines for good agricultural practices for keeping NH_3 emissions to the atmosphere at low levels have been published by the MAFF (1992).

Changes are taking place in agricultural practices in western Europe, and it is likely that NH_3 emissions will gradually diminish because:

- western Europe is mostly self-sufficient with animal products, and any marked future increases in the number of farm animals seems unlikely;
- the EEC nitrate directive will probably cause a gradually diminished animal population density and reduced intensity in pasture management in some regions;

- animal feeding tables are being revised to increase the N efficiency and reduce unnecessary excesses of N excretions;

- regulations for manure storage and spreading in some countries and regions with high animal densities should markedly reduce NH_3 emissions;

- improved manure utilisation together with reduced areas of agricultural land (the set-aside programme) will reduce the need for fertiliser application, perhaps with as much as 25% compared with the usage in 1990 (EFMA, 1991).

In contrast, application of sewage sludge is likely to increase, as sewage increasingly is given efficient treatment, and ocean dumping of sludge ended. Hence, this minor source of atmospheric NH_3 may increase in the future. However, this does not change the general impression, that western European emissions of NH_3 peaked around the time selected as reference year for this study: 1990.

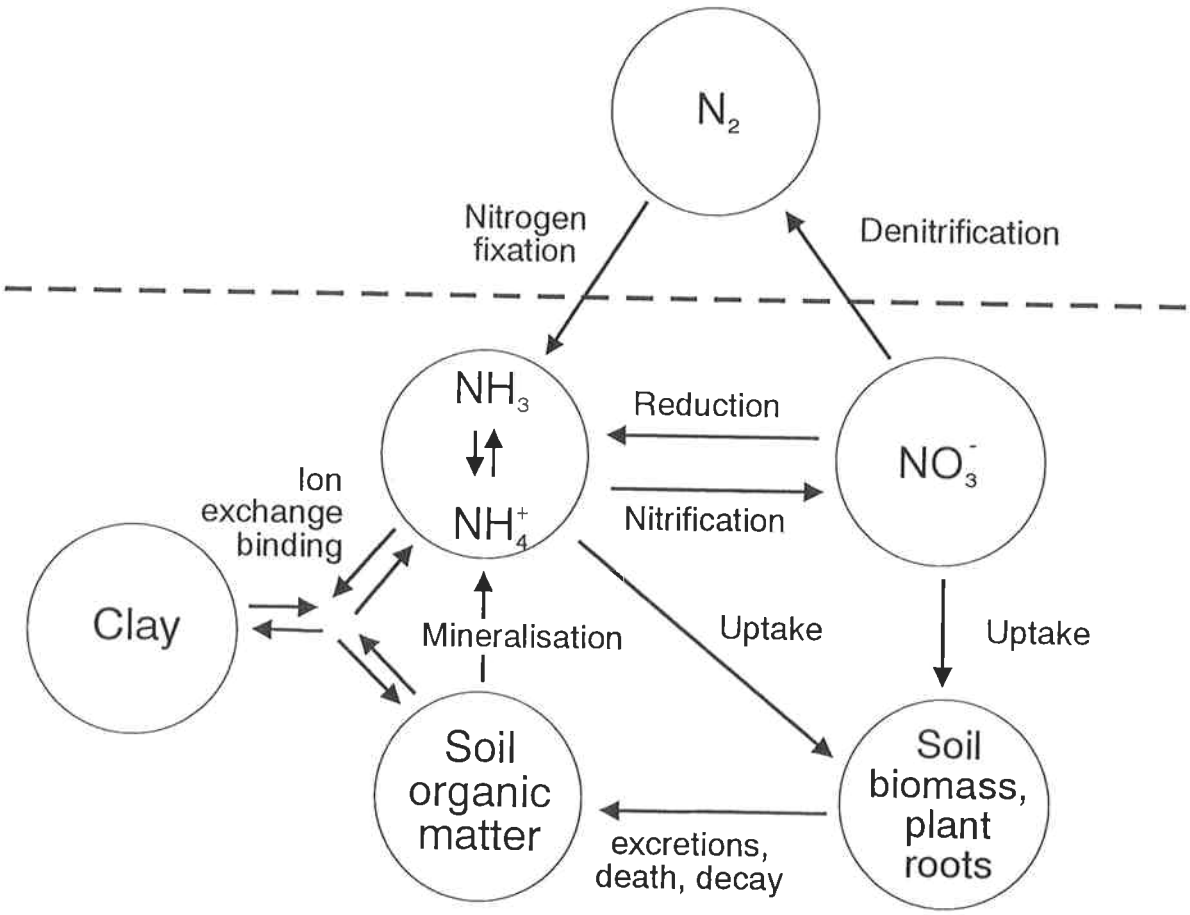
Changes in agricultural and animal husbandry practices will not be at the same rate in all European nations. It is difficult to predict such future rates as they to some extent depend on political developments. Hence an attempt to quantify in detail the expected diminishment in future NH_3 emissions and the time horizon for this decrease would be premature.

The potential for diminished NH_3 emissions in western Europe through adherence to good agricultural practices is substantial, especially for the losses after spreading of slurry. A future NH_3 emission level of 70 to 80% of the emissions in 1990 may be a realistic scenario. This implies a return to the emission level of the 1960's or early 70's.

APPENDIX A. SOME CONCEPTS AND PROCESSES IN THE NITROGEN CYCLE

N is a key element in all forms of life, but most organisms can not utilise atmospheric N as a gas (dinitrogen, N_2). It is only in its reduced (e.g. NH_4^+) or oxidised (eg. NO_3^-) states that N is generally available. The transformation of atmospheric N into forms useful for life processes, the many life processes that involve N, and the processes that re-form N_2 constitute a complex web called the N cycle. A simplified version of the N cycle indicates some concepts of the cycle used in this report (Figure A.1).

Figure A.1 The N Cycle



N fixation is the transformation of atmospheric N_2 to NH_3 or NO_3^-, both forms that can be taken up and utilised by microbes and plants. N can be 'fixed' by industrial processes (the Haber-Bosch process) or through microbial action (e.g. by bacteria belonging to the genera *Cyanobacteria*, *Rhizobium* or *Frankia*). The latter process is generally known as biological N fixation. Only some bacteria can fix N, no eucaryote has this biochemical capability (Sprent and Sprent, 1990).

Nitrification is the aerobic microbial process where NH_4^+ is converted to nitrite and further to nitrate. NH_4^+ oxidation to nitrate is usually done by bacteria belonging to the genus *Nitrosomonas* and the further oxidation of nitrite to nitrate by *Nitrobacter* sp., but other microbes including some fungi can also nitrify. Nitrous oxide can be produced as a byproduct.

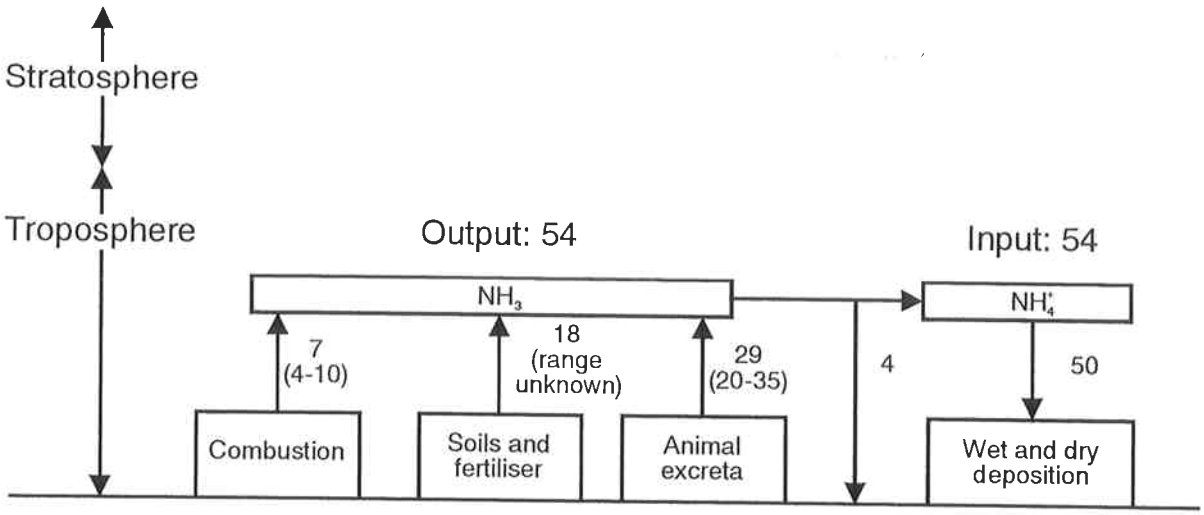
Mineralisation is the degradation of soil organic matter by microbes. The microorganisms use the organic matter as a source of energy, and N in the degraded matter that is in excess of the microbes need is excreted and thus made available to other organisms.

NH_4^+ binding in soil can take place through ion exchange with clays and acids in soil organic matter.

Denitrification is the final stage in the N cycle, where fixed N is returned to the atmospheric pool of N_2. Denitrification is mostly a microbial process, with nitrous oxide, N_2O, as an intermediate. Chemodenitrification (chemical decomposition of nitrite) can also occur.

A quantitative outline of the global N cycle with respect to NH_3 is given in Jenkinson (1990a) (Figure A.2).

Figure A.2 Global Production and Transformation of NH_3 (Mt NH_3-N/y) (Jenkinson, 1990a)



APPENDIX B. AMMONIA EMISSIONS FROM FERTILISER PRODUCTION

Tables B.1 and B.2 show the emissions of NH_3 and N-containing dusts based on 1988 fertiliser production figures.

Table B.1 NH_3 Emissions from Fertiliser Production

Country	Processed Total N (kt)	Finished fertiliser Total N (kt)	NH_3 emissions Total N (t)
Austria	687.2	247.0	378.6
Belgium	1,188.0	728.0	1,135.4
Denmark	270.7	190.6	402.9
Finland	427.0	281.2	650.8
France	3,419.3	1,507.0	1,985.2
Germany[a]	2,903.4	1,032.5	1,480.2
Greece	1,037.8	425.5	512.4
Ireland	578.7	285.9	770.9
Italy	2,828.7	1,316.5	3,331.9
Netherlands	4,656.1	1,755.3	3,628.9
Norway	1,012.0	426.0	905.1
Portugal	443.1	171.1	274.5
Spain	1,705.0	961.1	1,839.2
Sweden	221.7	163.2	259.4
Switzerland	78.7	32.0	39.4
UK	2,755.0	1,101.0	1,350.3
Totals	24,212.4	10,623.9	18,945.3
Ratio kg N/t N	0.782	1.783	

a East Germany (former GDR) not included

Table B.2 Emissions of N-Containing Dust from Fertiliser Production

Country	Processed Total N (kt)	Finished Fertiliser Total N (kt)	Dust Total N (t)
Austria	687.2	247.0	236.7
Belgium	1,188.0	728.0	544.1
Denmark	270.7	190.6	164.0
Finland	427.0	281.2	232.4
France	3,419.3	1,507.0	1,332.2
Germany[a]	2,903.4	1,032.5	805.1
Greece	1,037.8	425.5	431.6
Ireland	578.7	285.9	271.7
Italy	2,828.7	1,316.5	1,001.6
Netherlands	4,656.1	1,755.3	1,459.9
Norway	1,012.0	426.0	259.1
Portugal	443.1	171.1	143.3
Spain	1,705.0	961.1	776.2
Sweden	221.7	163.2	147.5
Switzerland	78.7	32.0	32.3
UK	2,755.0	1,101.0	1,066.5
Totals	24,212.4	10,623.9	8,904.2
Ratio kg N/t N	0.368	0.838	

a East Germany (former GDR) not included.

Due to different processing or differing equipment design and related circumstances, there is a very wide variation in emission factors. The final result given in the tables regarding loss ratios is a weighted average based on approximately 70% of all finished fertiliser N produced, and where emission data are available to EFMA. The remaining 30% are estimates, either for certain producing sites which have not given full emission figures related to their existing production, or estimates for production not covered by the EFMA study, like ammonium sulphate.

Data in the right-hand column represent the total emissions in 1988 for all manufacturing steps necessary to obtain all finished (saleable) fertilisers manufactured in each country and expressed as N. The total amount of finished fertiliser given by the middle column of data (expressed in total N contained) does not take into account the previous intermediate manufacturing steps of NH_3 or nitric

acid. These are taken into account in the first column, which also include emissions incurred during intermediate manufacturing steps. Hence, though the industry produces about 10 Mt of finished fertiliser N, it must process about 24 Mt of N to do this. This results in two different ratios (emission factors): for processed N, and for finished fertiliser.

These ratios refer only to emitted gaseous NH_3, and do not include NH_3 scrubbed by water and neutralised or recycled, or N included in dust emissions from drying or granulation operations where dust is abated by different means and recycled as far as possible.

Dust emissions are given in Table B.2 for comparison. N emitted as dust is mostly as urea or compounds containing NH_4^+ and/or NO_3^-, which do not usually give rise to NH_3 emissions except by secondary reactions in the soil as with applied fertilisers. The amounts emitted are less than gaseous releases of NH_3 and very small compared with the amounts of fertilisers applied annually. Hence losses from deposited dust can be regarded as insignificant in the total picture.

APPENDIX C. CALCULATION OF 1990 AMMONIA EMISSIONS FOR 17 COUNTRIES OF WESTERN EUROPE

C.1 INTRODUCTION

NH_3 emissions for EEC and EFTA countries were calculated with the help of spreadsheets. The basic construction of the spreadsheets is the same for all countries (Section C.2). General data sources and general assumptions are also given in Section C.2. The actual spreadsheets and additional, specific information is discussed for each individual country (Section C.3, Table C.7 and following). Entries can be located in the spreadsheets by means of their cell address (column and row number).

The basis for calculation of NH_3 emissions in the animal husbandry sector is the amount of N excreted by the animals. The calculation/estimation of N excretions and the emission factors (fraction of the N lost as NH_3) is described in the following section, with further details given in the national sections. The calculated emissions are summarised in Section C.19.

Results of measurements of NH_3 emissions vary within broad ranges. Calculations based on published results and estimates were made with all decimals in order to avoid the introduction of unnecessary computational distortions.

The accuracy of the estimates and the probable range of errors are discussed at the end of this appendix (Section C.20).

C.2 SPREADSHEET LAY-OUT AND GENERAL ASSUMPTIONS

In Column A are listed the sources of NH_3 emissions, including farm animals (Section C.2.1-2.5), fertiliser application (Section C.2.6), industry, crops and miscellaneous sources (Section C.2.7).

C.2.1 AMMONIA EMISSIONS FROM FARM ANIMALS

C.2.1.1 Category and Number of Animals (Column A and B)

The category and number of animals were taken from Eurostat for the countries of the EEC (Eurostat, 1992) and for EFTA countries national agricultural statistics have been used. The reference year for the number of animals in Column B is 1990. Where no data are available for

1990 then the data closest to the reference year are used. Details about minor deviations from the official statistics and from 1990 as the base year are found in the discussion on individual countries (Section C.3-18). The Eurostat Rapid Reports were used because the annual Eurostat Statistics for 1990 was not available due to delayed publication.

Some animal populations change during the year, also there can be minor differences between the various statistics (EEC, FAO, national statistics). The uncertainty induced by such differences are minor compared with those due to uncertainties in emission factors.

Column A lists 6 kinds of farm animals: cattle, pigs, sheep, goats, equine animals and poultry. It is known that cattle are the principal source of NH_3 emissions, followed by pigs and poultry (Buijsman *et al*, 1986). Therefore these 3 categories are further divided into appropriate subgroups.

Cattle

'Total cattle' are divided into those older than 2 years, yearlings (1-2 years) and calves (< 1 year). No distinction is made between cattle breeds.

Pigs

'Total pigs' is divided into 'Pigs for slaughter' and 'Boars and sows'. The latter does not contain 'Not mated sows' (Eurostat). This category is included in 'Pigs for slaughter'. The category 'Pigs for slaughter' excludes pigs smaller than 20 kg as these are fed by, or together with, the sow. The N excretion of these piglets is included with that of the sow.

Sheep, Goats and Equine Animals

The categories of 'Total sheep', 'Total goats' and 'Equine animals' (including horses and donkeys) are not subdivided, because they are relatively small and because little has been published about the environmental aspects of keeping goats, sheep and equine animals. Sheep populations oscillate as lambs are born in spring and slaughtered in autumn. The numbers are used as given in statistical tables, though they are not fully representative for all seasons. Numbers of equine animals for 1990 are mostly from FAO (1991). In some countries (e.g. Sweden and UK) the number of horses for riding have increased notably in later years, but they are not always included in agricultural statistics. Where this is so numbers have been obtained from national horse societies. It is mentioned in the text where such data have been used. Horses, mules and asses

are classified as equine animals. It was assumed that the N excretion of one horse is equal to that of one mule and that of two asses.

Poultry

The Eurostat Rapid Report gives no data for poultry. Hence data from the EEC survey of 1987 were used (Eurostat, 1990). National Statistics for 1990 have been used where available. This is indicated in the discussion on individual countries. It is assumed that the total number of poultry minus the number of laying hens is the number of table fowl.

C.2.1.2 Other Animals

There are some other farm animals that can be of local importance, but do not always appear in statistics: turkeys, geese, guinea fowl, rabbits and fur animals. Their contribution to NH_3 emissions can be of local significance (e.g. fur animals in parts of western Finland), but the NH_3 emissions from these sources on the European scale must be small. Allowances are made for these categories within emission from miscellaneous sources (Section 3.5 and C.2.7.3).

There is increasing interest in domesticating wild animals (e.g. deer, wild pigs) and rearing them in much the same way as ordinary farm animals. This has long been the tradition with fur animals such as fox and mink.

Reindeer are traditional domestic animals in northern Scandinavia, but they live in much the same way as their wild relatives. The populations of some deer are increasing, and they are managed and culled systematically. The borders between wild and domesticated animals are not sharp, but all these animals are excluded from this survey as outside the topic of anthropogenic emissions.

Pets are not insignificant in numbers, but they mostly live in cities and are included with the miscellaneous, mostly urban emissions.

C.2.2 CALCULATION FACTORS

C.2.2.1 Inside Winter and Summer (Column C and D)

Period of the year (fraction) cattle, sheep, goats and equine animals are housed and fed winter or summer rations.

C.2.2.2 Nitrogen Excretion in Summer and Winter (Column E)

For ruminants, N excretion can be greater in summer than in winter due to differences in feeding rations. This is so where the animals graze on intensively managed grassland or pastures rich in clover during summer. Where silage forms an important part of the winter feed or when animals are housed all year and mostly fed concentrate, this difference can be small or nil. The ratios of N excretion in summer and winter are estimated, based on research for the Netherlands (Section C.3.1.2) and discussion with colleagues in various other countries (Section C.4-18).

For sheep, goats and equine animals it is assumed that the ratio is the same as for cattle.

For pigs and poultry there is no difference in N excretion between summer and winter, because they have the same diet throughout the year. Thus 1.00 is given in Column C.

C.2.3 EMISSION FACTORS

Manure from cattle and pigs will be stored inside (beneath) the animal house, or in outdoor storage facilities. Both systems are in use. Indoor storage is most common in the colder climates; outdoor storage when the climate is warmer. No separation is made between animal house and storage emissions but both are combined as NH_3-N emission factors in Column F, G and O (losses from animal houses).

C.2.3.1 Animal Houses in Winter and Summer (exclusive of emissions from outside manure storages)

Climatic conditions in an animal house vary with season. A distinction is therefore made between emission factors for summer and winter. However, no distinction for season is made for pigs and poultry, which are kept under nearly constant conditions throughout the year, even though there may be a temperature difference in mechanically ventilated animal houses, causing higher emissions in summer than in winter.

The origin of these emissions is mainly the fast decomposition of urea in urine. Direct emissions from the animal (breath, flatus) also occur to a minor extent. Emissions include losses from manure stored within the animal houses where this is practiced. The extent of emissions depends on the animal category, husbandry practices, construction of the animal house and climatic conditions. The calculated emissions depend on animal N excretions. These excretions vary between countries as described in Section C.2.4. Further, a correction is made for the higher temperatures of

mediterranean countries compared with northern Europe, as described in Section C.8 (Italy). Hence shed emissions vary between countries.

A discussion of the basic literature for the calculation of emission factors is given under 'Netherlands' (Section C.3.2). Dutch data are used for all other countries unless otherwise stated. Emission factors in the spreadsheet columns are expressed in kg N per animal and day (kg N/hd/day). In order to simplify comparisons between countries and animal categories the shed emissions (exclusive of emissions from outside manure storage) are also given as percent of total N excretion in Table C.1.

Table C.1 Shed NH_3 Emissions, Exclusive of Outside Storage Emissions (% of total N excretion)

	Ruminants and horses		Pigs	Laying hens	Table fowl
	Winter	Summer	Annual	Annual	Annual
Austria	7.2	15.3	17.6	14.3	40.9
Belgium/ Luxembourg	7.2	15.3	17.6	9.1	15.7
Denmark	7.2	15.3	17.6	9.1	15.7
Finland	7.2	15.3	17.6	9.1	15.7
France	7.2	15.3	17.6	9.1	15.7
Greece	8.6	18.2	20.3	11.4	18.9
Germany	7.2	15.3	11.6	14.3	40.9
Ireland	7.2	15.3	17.6	9.1	15.7
Italy	8.6	18.2	20.3	11.4	18.9
Netherlands	7.2	15.3	18.3	9.1	15.7
Norway	7.2	15.3	17.6	9.1	15.7
Portugal	8.6	18.2	20.3	11.4	18.9
Spain	8.6	18.2	20.3	11.4	18.9
Sweden	7.2	15.3	17.6	9.1	15.7
Switzerland	7.2	15.3	11.6	14.3	40.9
UK	7.2	15.3	17.6	9.1	15.7

Outside Storage of Manure from Cattle and Pigs

Measurements of De Bode (1991) show that the measured emissions from outside storage depend on slurry type, storage time, temperature, wind speed, the size of the storage system and probably also on the measurement technique. The total N emissions varied between 3% for poultry slurry during winter and 15% for pig slurry during summer. The storage period varied between 180 and 250 days. The measured values are in accordance with other literature data. N emissions varying between 4 and 15% based on model calculations or on mass balances are reported (Patni and Jui, 1986; Muck and Steenhuis, 1982; Muck *et al*, 1984). The ABEF (1989) mentions emissions up to 10% of total N if slurry is stored for a longer period. In another experiment with cattle, Snel (1990) reported emissions of 28.5% for slurry stored for 184 days (from February to August) and of 18.1% for slurry stored for 245 days (from September to May). Sommer (1992) measured on average an emission rate of about 220 mg $NH_3/m^2/h$ using small storage systems. From his experiments it can be calculated that roughly 10% of the N is lost if the slurry is stored for half a year at an air temperature of 7°C. Also Isermann (1990a) assumes a emission rate of 10% for Germany. Therefore this value is used for those northern European countries where open storage is appropriate though the actual storage time may be lower or higher than 180 days.

In southern Europe, average temperature is higher. This results in higher manure storage losses, as shown by De Bode (1991). In Italy, storage capacity of slurry and manure is 120 to 180 days (Manstretta, 1991). Estimated emissions during storage are approximately 20% for an average storage time of 150 days. This factor is also used for Greece, Portugal and Spain, as it is assumed that conditions in those countries are comparable with those in Italy. For France, it was assumed that the emission rate is the average of the mentioned percentages, i.e. 15%.

NH_3 emissions from outside manure storage as % of total N excretion, for cattle and pigs are listed in table C.2. Where emissions are given as 0%, wastes are commonly stored inside or beneath the shed. Table C.2 also lists the combined storage and shed emissions (as % of total N excretion).

The procedure for calculating combined emissions from animal housing and manure storage is further explained in Section C.4.3.1.

C.2.3.2 Grazing (Column H)

Grazing animals include cattle, sheep, goats and equine animals (horses and donkeys), for which NH_3-N emissions are calculated. The emission factors in Column H are expressed as a fraction of the N excreted in dung and urine.

Table C.2 Shed NH_3 Emissions (Inclusive of Outside Storage) for Cattle and Pigs
(% of Total N Excretion)

	Storage	Storage and shed		
		Cattle		Pigs
	Annual	Winter	Summer	Annual
Austria	10	16.5	23.8	20.4
Belgium/Luxembourg	0	7.2	15.3	17.6
Denmark	0	7.2	15.3	17.6
Finland	0	7.2	15.3	17.6
France	15	21.1	28.0	30.0
Germany	10	16.5	23.8	20.4
Greece	20	26.9	34.6	35.9
Ireland	10	16.5	23.8	25.8
Italy	20	26.9	34.6	35.9
Netherlands	0	7.2	15.3	17.6
Norway	0	7.2	15.3	17.6
Portugal	20	26.9	34.6	35.9
Spain	20	26.9	34.6	35.9
Sweden	0	7.2	15.3	17.6
Switzerland	10	16.5	23.8	20.4
UK	10	16.5	23.8	25.8

Cattle

The most accurate measurements of NH_3 emissions from grazing are obtained by the use of micrometeorological methods. As these are expensive and labour intensive, there are only a few reports, but they point to similar emission levels.

In the Netherlands, Vertregt and Rutgers (1991) estimated an NH_3-N emission of 10% of the N excreted by cattle in urine and dung using the wind tunnel method. Bussink (1992) reported NH_3 volatilisation from a rotationally grazed sward in the Netherlands using the micrometeorological mass balance method. NH_3-N volatilisation from a sward dressed with 550 kg N/ha/year ranged 7.7-8.5% of excreted N, compared with only 3.1% at a sward dressed with 250 kg N/ha/year. Results from 1990 from swards dressed with 250, 400 and 500 kg N/ha/year were 3.3, 6.9 and

6.9% of excreted N lost as NH_3 (Bussink, 1994). As the measurement technique (micrometeorology with mass balance) gave too low results, the actual emissions may have been approximately 10% higher, as discussed by Bussink (1992). These results indicate that approximately 8% of N excreted with faeces and urine is lost as NH_3 under Dutch conditions with intensive grassland management.

Jarvis *et al* (1989a, b) and Jarvis and Pain (1990) described field experiments in the UK in 1986 and 1987, in which NH_3-N emissions from swards grazed by beef cattle were determined. Measurements were made on swards rotationally or continuously grazed by beef cattle and fertilised with 420 or 210 kg N/ha/year. Measurements were also made on unfertilised grass-white clover swards where N fixation by clover provided about 160 kg N/ha/year. Thus, the N input averaged over all experiments in both years was about 265 kg N/ha/year. The average weight of the individual yearling steers was 200 kg. The total amount of N excreted in faeces and urine was 0.128 kg/hd/grazing day, averaged over all treatments in both years. If the production and N content of faeces and urine/hd/day were constant over the whole year, total N excretion/hd/year would be 46.8 kg. The average NH_3 emission over all treatments in both years was 0.011 kg N/hd/grazing day or 8.5% of the amount excreted. Jarvis (1989b) estimated for the British situation, with an average N fertiliser application of 200 kg/ha to grassland, an average emission of 8% of the excreted N.

The Dutch value of 8 % agrees well with results from the UK though the intensity was lower than in the Netherlands. The same factor (8 % or 0.08) is used for all cattle and for all countries, due to lack of national data for most countries.

Sheep and Goats

Jarvis *et al* (1991) published some data on micrometeorological measurements of NH_3 emission from swards in the UK continuously grazed by sheep (Table C.3).

On average he calculated a daily emission of 1 g/ewe/day, which is approximately equal to 1.4% of total N excretion (an ewe excreted > 3 to 102 g N/day (Parsons *et al*, 1991). These amounts are very low in comparison to NH_3 emissions from cattle at comparable N inputs. There is no clear reason for this difference, very low NH_3 emission rates are difficult to measure by micrometeorological methods. Higher emissions have been reported. In Australia (Denmead *et al* (1976)). NH_3 volatilisation measurements were made on a grass-clover pasture, using a micrometeorological method. An average daytime emission of 13 g N/ha/h was found on an area grazed by sheep (90 sheep/ha). The average daytime loss of NH_3 from an ungrazed area was only

Table C.3 NH_3 Emissions From Swards Grazed by Sheep at Different N Input Regimes (Jarvis *et al*, 1991)

Management	NH_3 losses (g N/hd/d)		
	1988	1988	1989
Grass + 420 kg N/ha	1.208	1.237	1.261
Grass + 0 kg N/ha	-	0.838	0.992
Grass-white clover + ON	0.131	0.162	0.226

2 g N/ha/h. A rough calculation shows that the emission as a percentage of the N-excreted could vary between 5% (100 x 365 x (0.013-0.002) x 13h) / (90x12) and 10% (100 x 365 x (0.013-0.002) x 13h) / (90x6), for an annual N excretion of 6 and 12 kg respectively.

In New Zealand (Sherlock and Goh, 1984) average emissions of 22% of the urine N were found, using an enclosure technique. However environmental and herbage production conditions in those countries differ from north-west Europe.

Despite the difference in environmental conditions, an emission factor of 1.2% is unusually low, notably when compared with the emission factor of 8% for cattle. However, since sheep in most countries commonly do rough grazing at least some of the time, and since the N intake with rough grazing is likely to be less than that obtained from intensively managed pastures, a reduced emission factor seems appropriate. The approximation is therefore made that an intermediate factor (1.2 + 8)/2 = 4.6% will be an appropriate factor for sheep at pasture.

Since sheep are of relatively minor importance as an NH_3 source the inherent uncertainty in this assumption will not markedly affect the final result.

The emission factor (0.046) assumed for sheep is also used for goats for all countries, as there are no studies on goats available.

Equine Animals

For horses, this factor is assumed to be equal to that for cattle (0.08).

It can be argued that equine animals should be excluded as the proportion of horses, mules and asses that are grazed is unknown. However most equine animals do some grazing, and as their population is comparatively small, the rough assumption made seems justified.

C.2.3.3 Spreading (Column I)

Spreading emission factors refer to the N applied in manure (listed in Column N: Total slurry). Emissions of NH_3 from manure spreading is the largest single source of loss, but also the most variable, depending on methods of application and on soil and weather conditions. There are 2 main forms of livestock waste: slurry (droppings, urine and waste water from animal houses) and farmyard manure (droppings, urine and straw).

The most important differences in composition between farmyard manure and slurry are (MLV, 1987):

- Farmyard manure has a much higher dry matter content than slurry. In the Netherlands the dry matter content of farmyard manure is 2-3 times higher than that of slurry.

- The mineral N content of slurry is approximately 2-3 times higher than that of farmyard manure (due to NH_3 immobilisation by the straw and NH_3 losses during farmyard manure storage). Mineral N is mainly present as NH_4^+, both in farmyard manure and slurry.

- Farmyard manure has a higher content of organic N than slurry. Only approximately 50% of this organic N is easily decomposable.

The high NH_4^+ content of slurry, compared to farmyard manure leads to a relatively greater risk of NH_3 emission. However, Amberger (1990) and Ott (1990) found that N emissions from surface-applied fresh farmyard manure and partly decomposed farmyard manure were within the range of NH_3 losses from slurry, if the whole chain from the excretion until and including application is considered. Hence no differentiation is made between farmyard manure and slurry, as also discussed in Section C.2.3.3.

Here 4 different sets of estimates for spreading emissions are used, described for the Netherlands, Germany, the UK and Denmark (Section C.3, C.4, C.5 and C.13).

C.2.4 NITROGEN EXCRETION

C.2.4.1 Total Nitrogen Excreted Per Animal (Column J)

The amounts of N excreted are expressed as kg per head per year (kg N/hd/year).

Cattle Older than 2 Years (Cell J12)

The manure production and N excretion per cow increase with increasing milk production and with increasing N content of the feed.

The N excretion per cow is used for the calculation of NH_3 emissions (column J). The N excretion can be estimated using the results of Kirchgessner *et al* (1991). They summarised results from feeding experiments with lactating cows in the regression Equation C.1.

$$N_{excretion} = 61 + (X + 550) \times (1.65Y - 20.5) / 1{,}000 \qquad \text{(Eq. C.1)}$$

where:-

X = average milk yield per cow (kg/year)

Y = crude protein content of the diet (% of dry matter)

The recommended feed content of crude protein varies somewhat with breed and national conditions.

A crude protein content in the feed of 17% is used as a best estimate for calculations using Equation C.1 for estimates of N excretion/cow in the various countries (Table C.4).

The estimate is too high for Norway, approximately right for Germany and too low for Denmark, Netherlands, Switzerland and the UK.

The estimate is likely to be too low where the production is based on well fertilised grassland with high N content and too high when the production is more extensive.

Klaassen (1992b) also derived country specific emission coefficients based on N excretions. The estimates of cattle N excretion was based on fertiliser N application rates for grassland. However, the application level varies within countries, and cows do not only get herbage but also variable but

Table C.4 Average N Excretion/Cow

	Milk production[a] (1,000 Mt)	Dairy cows[b] (x 1,000)	Average milk production (kg/cow/y)	N excretion[c] (kg/cow/y)	
Austria	3,360	945	3,556	92	
Belgium/Luxembourg	3,810	880	4,330	98	
Denmark	4,730	769	6,151	112	(129)
Finland	2,730	505	5,406	106	
France	26,000	5,271	4,933	102	
Germany	32,825	6,355	5,165	104	(101)
Greece	670	242	2,769	86	
Ireland	5,605	1,322	4,240	97	
Italy	10,376	2,881	3,602	92	
Netherlands	11,180	1,917	5,832	109	(134)
Norway	1,912	334	5,725	108	(84)
Portugal	1,544	396	3,899	95	
Spain	6,100	1,575	3,873	94	
Sweden	3,523	567	6,213	112	
Switzerland	3,772	785	4,805	101	(110)
UK	15,284	2,890	5,289	105	(122)

a FAO statistics for 1990 (FAO, 1992)

b Data for EEC countries from Eurostat Rapid Reports (1993, No.6), data for other countries from FAO statistics for 1990 (FAO, 1992)

c Published values are given in brackets (Denmark: Koefoed and Hansen, 1991; Germany: BML, 1991; Netherlands: Mandersloot, 1992; Norway: Sundstøl and Mroz, 1988; Switzerland: Menzi *et al*, 1992. For the UK, it can be calculated from the results of Jarvis (1993) that a cow with a milk yield of 5,554 kg/year excretes 130 kg N/year, calculated by adding the cow values in Table 4 of Jarvis and then dividing by 102 (the number of cows). Extrapolation to 5,289 kg/year gives 122 kg N/cow/year.

generally substantial amounts of concentrates. Hence the approach used by Klaassen introduces great uncertainties into the estimates and probably gives an under-estimation of NH_3 emissions.

In some regions, cattle for meat production form a significant portion of all cattle. Their N intake is lower than for dairy cows but so is the N efficiency. Hence the N excretion may be comparable. No differentiation is made between beef and dairy cattle.

For the calculations in Column J, published numbers from Table C.2 are used where such are listed. Otherwise calculated values for N excretion is used.

Feeding practices vary within nations and both published values and the estimates are uncertain. The consequences of this inherent uncertainty for the conclusions are discussed in the sensitivity analysis (Section C.20).

Young Cattle (Cell J13-14)

Mandersloot (1992) reported N excretion by young cattle (1-2 years) and calves (< 1 year) fed grass or grass silage with some additional concentrates (10-20% of feed) (Table C.5).

Table C.5 N Excretion of Young Cattle and Calves (Mandersloot, 1992)

N input to grassland (kg N/ha/y)	N excretion (kg N/hd/y)	
	Young cattle (1-2 y)	Calves (< 1 y)
200	76.5	33.2
300	86.6	36.1
400	95.5	38.1

The N input to grassland is highest in the Netherlands and UK. 87 kg N/hd/year is therefore used for young cattle and 36 kg N/hd/year for calves (Column J) for the Netherlands and UK. For other countries 76 kg N/hd/year and 33 kg N/hd/year are used for these categories, corresponding to an annual input of 200 kg N/ha of grassland used for feeding the calves. This may give an overestimate in some instances.

Pigs (Cell J17-18)

In the Dutch situation a fattening pig excretes 4.48 kg N. With 3.05 cycles/year, this means a total N excretion/fattening pig place of 13.6 kg N/year. Productive sows in the Netherlands (breeding sows excluding not-mated gilts) excrete about 22.7 kg N/year. A sow produces on the average 19.5 piglets, each of which excretes 0.56 kg N. A sow including the piglets excretes thus approximately 33.6 kg N/hd/year (Coppoolse *et al*, 1990).

A fattening pig in Denmark excretes 4.1 kg N. With 3 cycles/year the N excretion per pig place becomes 12.83 kg N/year. A productive sow (including 21 piglets) excretes 38.9 kg N/hd/year (Koefoed and Hansen, 1991).

According to the BML (1991) the N excretion/pig place in Germany is 12.8 kg N/year. Productive sows (including piglets) excrete 33 kg N/hd/year.

The data for these 3 countries are similar. For the countries where there are no data available the German data are used, except for Italy (Section C.10).

Sheep and Goats (Cell J20-22)

Reports on N excretion of sheep ranges from 12 kg N/hd/year (Buijsman *et al*, 1986), 16 kg N/hd/year (Menzi and Besson, 1991) to 18.6 kg N/hd/year (calculated from Zimmerman and Sciborski, 1989). However if sheep are grazing on well fertilised pasture or grass-clover swards, N excretion may be much higher. Parsons *et al* (1991) measured daily N excretion of 73 up to 89.7 g/ewe on grass-clover swards and 101.7 g/ewe on a sward receiving 420 kg N/ha/year. This is equal to an annual N excretion of 26.6-32.8 kg N/ewe and 37.1 kg N/ewe respectively.

A value of 12 kg N/hd/year may be realistic for sheep that are grazing on rough pasture. In Europe, sheep are mostly rough grazing in some regions, while pastures are fertilised in others. As quantitative details are not available for all Europe, an average excretion of (12 + 16 + 18.6)/3 = 15.5 kg N/hd/year is used, except for the Netherlands and Denmark, where (15.5 + 37.1)/2 = 26.3 kg N/hd/year is used because sheep there graze mostly on well-fertilised pastures, and for the UK where approximately 20% of sheep graze on fertilised pastures (0.8x15.5 + 0.2x26.3) = 17.7 kg N/hd/year.

The number of sheep vary during the season due to lambing in spring. Normally most of the lambs are slaughtered in autumn. Therefore few lambs are included in the Eurostat December statistics of 1990 (Eurostat, 1992). On average an ewe produces 2 lambs. According to Parsons *et al* (1990) the average daily N excretion of a lamb from birth to 5 months is 30 to 40% of that from an ewe. If it is assumed that a lamb is slaughtered 5 months after birth, then N excretion/ewe including lambs amounts to respectively: 26.3x(1+2x0.35x5/12) = 34 kg N/hd/year, 17.7x(1+2x0.35/12) = 23 kg N/hd/year and 15.5x(1+2x0.35x5/12) = 20 kg N/hd/year for the Netherlands, UK and all other countries. These values are used in the spreadsheets.

Goats deliver 2 kids in spring, males are soon slaughtered in autumn. Goats are mainly kept for milk production while sheep are kept for meat, but on average the same data and calculation principles for NH_3 emissions seem appropriate for these 2 groups of animals.

Poultry (Cell J27-28)

Poultry is divided into two categories: Laying hens and table fowl. A light hen (1.8 kg) excretes approximately 720 g N/year and a middle heavy hen (2.2 kg) approximately 812 g N/year (Coppoolse *et al*, 1990). On average 766 g N/year is excreted by laying hens. A broiler excretes about 69 g N/44 day. There are approximately 6.6 broiler cycles/year, thus total N excretion becomes 455g/broiler)/year

In the experiments of Kirchgessner and Kreuzer (1990) in Germany, the N excretion of laying hens (1.6 kg/hd) was approximately 775 g N/hen/year if they were fed with feed containing intermediate protein levels. Broilers excreted about 36 g N/5 week if they were fed with feed containing intermediate protein levels. In Germany broilers are killed at a younger age, consequently there are approximately 8.1 cycles/year, amd annual N excretion then becomes 292 g N/broiler/year.

The BML (1991) uses respectively 710 g N/hen/year and 270 g N/broiler/year as common values for N excretion of laying hens and broilers in Germany.

For laying hens, Dutch and German N excretion data are in close agreement. For the countries where there are no data available the Dutch value of 766 g N/hen/year is used.

For broilers there is a large difference in N excretion between the 2 countries. This is mainly caused by the difference in dietary N content and the fattening time per broiler. For example a fattening period of 8 weeks instead of 5 weeks would result in a N excretion of 73 g N/broiler, which corresponds with an annual N excretion of 404 g N/broiler. In Germany, fattening for a period of 8 weeks is common as well as fattening for 5 weeks (Kirchgessner and Kreuzer, 1990). The estimate is made that the average N excretion is (292 + 404)/2 = 348 g/broiler/year. The average German value has been used where no data are available for a country.

C.2.4.2 Nitrogen Excretion Within the Animal House (Column K)

Waste excreted in the animal house can be collected and used in a controlled manner, in contrast to animal droppings during grazing. Therefore the amounts of N excreted in and outside the animal house are both calculated in kg N/hd/year, using the factors previously listed, which is the fraction

of the time that the animal is in the animal house multiplied with total N excretion. For example, that of pigs and poultry (K17), is the product of Calculation Factor - Winter Inside (C17) and Nitrogen Excretion - Total Kg N/hd/year (J17).

$$K17 = C17 \times J17 \qquad \text{(Eq. C.2)}$$

For grazing animals the fraction of the time in the animal house has to be weighted for N excretion, because there is a difference between summer and winter diet. For cattle > 2 years (Row 12) this is for example:

$$(C12 + D12 \times E12) / (C12 + E12 \times (1-C12)) \qquad \text{(Eq. C.3)}$$

Multiplying this with J12 gives total N excretion in the animal house in kg N/hd/year.

C.2.4.3 Nitrogen Excretion Outside the Animal House (Column L)

An example of the calculation of the amount excreted outside the animal house and during grazing for cattle > 2 years (Cell L12) is:

$$L12 = J12 - K12 \qquad \text{(Eq. C.4)}$$

Pigs and poultry are mostly stabled all year, and the cells L17 and 18 becomes 0.00.

C.2.4.4 Total Nitrogen Excretion (Column M)

The total amount of N excreted in the animal house by each animal group can now be calculated by multiplying Column B with Column J. Division by a factor 1,000 gives the amount of N in kt. An example is the calculation of a value for cattle > 2 years (Cell M12):

$$M12 = B12 \times J12 / 1{,}000 \qquad \text{(Eq. C.5)}$$

C.2.4.5 Total Nitrogen in Slurry (Column N)

In Column N the amount of slurry N available is calculated at the moment of spreading. It is the amount excreted in the animal house minus emissions. It is given in kt and calculated for ruminants in, for example, cattle > 2 years (Cell N12):

$$N12 = B12 \times (K12-(C12 \times F12 + D12 \times G12) \times 365) / 1{,}000 \quad \text{(Eq. C.6)}$$

For pigs and poultry the calculation should take into account that the excretion is split in 2 seasons for calculation purposes, for example, pigs for slaughter (Cell N17):

$$N17 = B17 \times (K17-(C17 \times F17 + C17 \times G17) \times 365 / 2) / 1{,}000 \quad \text{(Eq. C.7)}$$

C.2.5 AMMONIA-NITROGEN EMISSIONS

C.2.5.1 Ammonia-Nitrogen Emissions from Animal Houses, Surface Spreading and Grazing (Column O, P and Q)

This list the emissions according to the principal source; from the animal houses with or without storage losses, slurry spreading and grazing. It is assumed that in the reference year no injection, or soil tillage immediately after surface spreading, took place. Such incorporation will become more common, more so in some regions, than in others, but reliable estimates on the extent of manure incorporation are not available. These emissions are calculated from the values in the tables, for example cattle > 2 years (Cell O12-Q12):

Animal houses: $$O12 = ((B12 \times K12) / 1000) - N12 \quad \text{(Eq. C.8)}$$

Spreading: $$P12 = I12 \times N12 \quad \text{(Eq. C.9)}$$

Grazing: $$Q12 = B12 \times H12 \times L12 / 1000 \quad \text{(Eq. C.10)}$$

(This equation is only relevant for cattle, sheep, goats and equine animals.)

C.2.5.2 Total Ammonia-Nitrogen Emissions (Column R)

The principal emissions from animal houses, spreading and grazing are added in Column R to give the total NH_3-N emissions in kt N/year.

Total: $$R12 = O12 + P12 + Q12 \quad \text{(Eq. C.11)}$$

C.2.5.3 Ammonia-Nitrogen Emission as a Percentage of Nitrogen Excreted (Column S)

In this column NH_3-N emissions are listed as percentages of the amount of excreted N. An example is the calculation of a value for cattle > 2 years (Cell S12):

$$S12 = 100 \times R12 / M12 \qquad \text{(Eq. C.12)}$$

C.2.5.4 Ammonia-Nitrogen Emission per Category (Column T)

Emission/hd/category expressed as a percentage of total NH_3-N loss (animals plus mineral fertilisers plus industry, crops and miscellaneous and humans). An example of the calculation of a value for total emissions by cattle (Cell T11):

$$T11 = 100 \times (R12 + R13 + R14) / R49 \qquad \text{(Eq. C.13)}$$

C.2.6 AMMONIA EMISSIONS FROM FERTILISER APPLICATION

C.2.6.1 Emission Factors and Soil Characteristics

Emission factors for N-containing fertilisers should preferably take regional soil conditions into account. Four such factors seems especially important for the propensity of a soil to lose NH_3 after fertiliser application: the pH, the amount of Ca^{2+} available for reaction, the soils cation exchange capacity (CEC) for adsorption of NH_4^+ and the soils buffer capacity (Freeney *et al*, 1983).

Previous estimates of NH_3 losses from fertiliser application use emission factors that differ in some details, (Table 12 of main text). The emission factors of Buijsman *et al* (1986), used also by Istas *et al*, (1988), Fabry *et al*, (1990) and Klaassen (1992b)), refer to laboratory experiments on soils were pH mostly were above 7 designed to illustrate the effect of soluble calcium salts on NH_3 volatilisation (Fenn and Kissel, 1974b; Fenn *et al*, 1981a,b; Fenn and Miyamoto, 1981). Hargrove and Kissel (1979) found that field measurements indicated lower emissions than those expected from laboratory studies (field losses 0-9% of applied N compared to laboratory losses of 13-31%). In only a few experiments has NH_3 volatilisation from mineral fertilisers been determined directly under field conditions (Denmead *et al*, 1977; Hargrove *et al*, 1977; Black *et al*, 1985; Ryden *et al*, 1987; Amberger, 1990; Velthof *et al*, 1990).

Data found in the literature show a large variation in N emissions through NH_3 volatilisation from NH_4^+ containing, or generating, mineral fertilisers. These losses are strongly dependent on

management, soil and environmental factors, such as application method and rate, $CaCO_3$ content and CEC of the soil, and rainfall (Hargrove, 1988).

The soil pH as published is not a well defined parameter. Results of measurements depend to some extent on the analytical method, this differs between nations and authors. This difference in methodology complicates comparisons of published values. There is no well defined narrow pH range where the NH_3 emissions abruptly increase but in general the potential for NH_3 losses increase markedly when the pH exceeds about 7 (Freney *et al*, 1983), Ventura and Yoshida (1977), Whitehead and Raistrick (1990). Calcareous soils are prominent among soils having a pH > 7.

Soil maps provide an indication of where calcareous soils in Europe can be found. In north western Europe calcareous soils are most common in some coastal areas and in lower regions of river valleys (Kværner and Brunstad, 1991). Calcareous soils are especially common in Spain and Greece, but substantial parts of agricultural soils in e.g. France and Netherlands also have high pH.

Soil characteristics of arable land does not necessarily correspond closely with those of natural soil, as liming, fertilisation, rotation and other management practices can change the soil pH appreciably. This limits the usefulness of soil classification maps as a basis for estimating the prevalence of agricultural soils with high pH. Thus 66% of the arable soils in England and Wales have a pH of 7 (water) and above, while only 11% of grasslands have such a high pH (Skinner *et al*, 1992). In general grasslands tend to be more acidic than arable land. Within a country soil chemical properties can differ markedly within regions.

Also a high soil pH does not necessarily imply a calcareous soil, as clay soils can have a pH well above 7. However, clay soils have a considerable capacity for binding NH_4^+ through ion exchange and are thus less prone to NH_3 emissions than calcareous soils.

National emission factors will give a rather crude estimate, but should still be preferable to standard European factors, because the difference in soils and soil conditions between the somewhat acidic (pH 6) soils common in northern Europe and the Mediterranean calcareous soils (pH 7.0-8.0) is sufficiently large to make the use of common factors somewhat questionable.

Calcareous Mediterranean soils are common in Greece and Spain. This together with high temperatures compared with northern climates indicate that the potential for NH_3 emissions in this region (Group I) must be regarded as high.

Soils with a pH above 7 are not common in the Nordic countries, Germany, Switzerland and Austria. Emission factors reflecting a low tendency for the soils in this region (group III) to lose NH_3 is therefore appropriate.

The remaining nations (Group II: Italy, France, UK, Eire, Portugal, Belgium, Netherlands and Luxemburg) have fertilised areas that are calcareous or otherwise have a pH of 7 or above, but also large tracts with more acidic soils. They form a group of nations with soils having intermediate NH_3 emission potential.

This grouping can only be regarded as a first approximation. There is a noticeable lack of data for NH_3 emissions under Mediterranean conditions. Though better data would be desirable, refinements of the emission factors are unlikely to change markedly the estimates of total NH_3 emissions, as emissions from fertiliser application are only a minor source of atmospheric NH_3.

C.2.6.2 **Category and Emission Factors** (Cell A36-40 and I36-40)

The emission factors used by other authors are listed in Table 12 of the main text. Generally they are similar, but with some differences in detail.

For simplicity fertilisers with the same emission factors are grouped together. Thus 5 categories are listed: Urea, Ammonium Nitrate (including CAN, NP-N, NK-N and NPK-N except for Ireland), Ammonium Phosphate, Ammonium Sulphate, and Other N fertilisers. In Denmark other N fertilisers consist mainly of anhydrous ammonia, in Ireland compounds. For France, Spain and the UK Other N fertilisers will mainly be N solutions and the emission factors appropriate for these are used.

As the discussion is based on the IFA statistics, the individual fertilisers and the evidence for the emission factors are discussed in the order they are listed in the statistics.

Ammonium Sulphate

This fertiliser is highly susceptible to NH_3 emissions on calcareous soils. Ammonium sulphate reacts with $CaCO_3$ to form the relatively insoluble $CaSO_4$ and ammonium bicarbonate, which in turn may decompose to NH_3 (Fenn and Hossner, 1985 and Fenn and Kissel, 1974a, 1975).

On non-calcareous soils ammonium sulphate is not more prone to NH_3 volatilisation than other ammonium based fertilisers, (Whitehead and Raistrick, 1990). NH_3 emissions from application of

ammonium sulphate thus vary greatly with soil and climatic conditions, with published values ranging from negligible to 50-60%, (Hargrove *et al*, 1977, Terman, 1979; Demeyer, 1992).

Ammonium sulphate is used to a limited extent in southern Europe (Greece, Italy, Spain and Portugal) where it represents 6 to 10% of applied N, and in the eastern parts of Germany. In the rest of western Europe it is a special product, representing less than 3% of fertiliser use.

The information that can be used for estimating emissions is limited. Buijsman *et al* (1986) used 15% (based on reported experiments with calcareous soils), Asman (1992) 8%. A more differentiated set of factors are used in the present report: 5% for countries with little calcareous soil, 10% for those in the middle range and 15% for those 2 nations (Spain and Greece) where calcareous soil are common. In view of the very limited use of this fertiliser experimental effort to improve this estimate does not seem worthwhile, except perhaps for calcareous soil under Mediterranean climatic conditions. This may be an overestimate for regions where calcareous soils are comparatively rare, and where clay soils account for much of the area with soil pH > 7. On clay soils losses should be reduced, due to ion exchange. This possible overestimate will not markedly influence the total estimate as only little ammonium sulphate is used in this regions.

Urea

As described in the main part of the report, the use of urea is on the increase in some European countries, but it still represents only 18% of the application.

Its propensity for NH_3 emission is due to its rapid (within a few days) enzymatic hydrolysis to ammonium bicarbonate, a compound that decomposes and releases NH_3. Also, the soil pH near the granule will increase during the hydrolysis. Thus urea has been reported as being less efficient than other nitrogen fertilisers, e.g. ammonium nitrate, when used as top dressing. Such lower agronomic value (some 75-90% of that of ammonium nitrate, Van Burg *et al*,1982) is mainly due to NH_3 vaporisation. However, there are also comparative field trial results that show no marked difference in N efficiency between urea and other N fertilisers.

Regions with frequent rainfalls seems to be less prone to NH_3 volatilisation following urea application than areas with drier climates (Stevens *et al*, 1989b; Bussink, unpublished observations).

Urea is the fertiliser with most pronounced tendency towards NH_3 loss, and more work has been done on this product than on any other fertiliser. The results show great variability, and estimates of typical emissions carry a substantial margin of uncertainty.

The emissions are, as with all NH_3 volatilisation, dependent on weather (rainfall, temperature and wind patterns), and will thus vary from region and from year to year. Incorporation into the soil at a depth of 5-10 cm or below will greatly reduce NH_3 volatilisation (Bock and Kissel, 1988), but volatilisation losses seem to be almost independent of fertiliser granule size (Watson and Kilpatrick, 1991).

While NH_3 volatilisation is most pronounced on alkaline soils, conditions (enhanced pH) favourable for NH_3 volatilisation develop even in acidic soils when urea is hydrolysed. High concentrations of soluble Ca^{2+} in the soil (or fertiliser) can retard NH_3 losses through reactions with the intermediate ammonium bicarbonate and precitation of $CaCO_3$. This reaction has an acidifying effect (Hargrove, 1988):

$$Ca^{2+} + HCO_3^- \rightarrow CaCO_3 + H^+ \qquad \text{(Eq. C.14)}$$

Whitehead and Raistrick's (1990) laboratory experiments indicated that under British conditions 16.5% was lost in grassland, and approximately 11.5% from arable land where some incorporation takes place. This is similar to the loss (approximately 15%, Whitehead, 1990) found for N in urine from grazing animals in the UK. The tendency towards frequent rains in the UK should contribute towards reducing the emissions. Ammoniacal emissions from urea increases when urea is applied to the soil under warm and rather dry climatological conditions (for example Ryden *et al*, 1987; Velthof *et al*, 1990 and the reviews of Terman, 1979; Fenn and Hossner, 1985).

The physical chemistry of the increased volatilisation observed when the temperature rises is discussed in Section 1.2.3 (Figure 3) of the main text. Rachpal-Singh and Nye (1986) have developed a mathematical model for calculating NH_3 volatilisation from applied urea.

An important use for urea is as fertiliser for rice, where losses tend to be severe, as paddy rice water is usually alkaline. Models are available for calculating emissions under a variety of agricultural conditions (Jayaweera and Mikkelsen, 1991). Much of this work has been done under tropical conditions and can not be directly used for European estimates, but they indicate large losses ranging 27 to 54% of urea applied to paddy rice in the Philippines (Fillery *et al*, 1984; earlier work reviewed by Fillery and Datta, 1986; Fillery and Vlek, 1986; De Datta *et al*, 1991).

The extent of NH_3 losses from paddy fields has been a topic of some controversy (Koshnio, 1989). Studies in Thailand indicated that losses there from broadcast urea were insignificant. In Europe paddy rice is cultivated mainly in Italy, Spain and Portugal (2.4% of cereal area). There is also some production in Greece and France but on an insignificant scale. The comparatively small areas under rice does not justify a special treatment for this type of production as an NH_3 source in Europe.

NH_3 volatilisation from surface applied urea in temperate climates has been measured in the field, using wind tunnel or micrometeorological methods (Gasser, 1964; Black *et al*, 1985; Ryden *et al*, 1987; Christensen and Sommer, 1989; Amberger, 1990; Velthof *et al*, 1990). There have also been many measurements of NH_3 volatilisation from urea under controlled conditions (see for example Stevens *et al*, 1989b, Whitehead and Raistrick, 1990 and the reviews of Terman, 1979; Fenn and Hosner, 1985). Using the data in literature, it can be estimated that the average NH_3 emission factor for surface applied urea is about 10-25%. Asman (1992) uses 15% as standard emission factor while Schlesinger and Hartley (1992) presents arguments for 20% as a representative factor world-wide.

As the published results indicate that emissions can be somewhat higher from soils with high pH in warm climates than from non-acidic soils and in temperate regions, emission factors of 20% is used for group I, and 15% for the rest of Europe. Comparative field trials of urea compared with other N fertilisers that includes measurements of NH_3 emissions would be welcome, particularly from the mediterranean area.

Ammonium Nitrate (AN) and Calcium Ammonium Nitrate (CAN)

Ammonium Nitrate (AN) and Calcium Ammonium Nitrate (CAN) are the principle forms of N used in European agriculture, accounting for approximately 50% of the application. Calcium ammonium nitrate is ammonium nitrate diluted with 20-25% calcium carbonate or dolomite.

When the fertiliser particles dissolve on the soil surface and the nitrogen salts drain into the soil, the insoluble limestone is left on the surface and does not markedly influence the further fate of the ammonium nitrate. It is therefore not expected that CAN and AN should differ markedly in their tendency to loose NH_3 after application, but studies on this topic are lacking.

Only half of the N in ammonium nitrate is in the form of NH_4^+. The nitrate N does not contribute to volatilisation. The emission factors are expressed as % of total N. In order to calculate the volatilisation as % of applied NH_4^+-N, the numbers should be doubled.

The number of experiments with this fertiliser is small compared with the amount of work published on NH_3 emissions from urea and also that of ammonium sulphate. Lightner *et al* (1990), Ryden *et al* (1987), Velthof *et al* (1990), Flieg *et al* (1939) found that N losses through NH_3 volatilisation from calcium ammonium nitrate and ammonium nitrate were less than 5% (and mostly less than 2%) of the total N applied when these fertilisers were surface applied to non-calcareous soil. Only on calcareous soils could higher emissions of NH_3 be expected, up to 10% (Hargrove *et al*, 1977). Whitehead and Raistrick (1990) found a marked dependence of volatilisation on soil acidity. The loss was less than 1% for 3 soils with pH of 3.7, 5.5 and 6.1, but amounted to 8-10% for 2 soils with pH of 7.1 and 7.4. These experiments were conducted in the laboratory and not in the field and probably overestimate the emissions. Under their experimental conditions the loss of NH_3 was less from ammonium nitrate than that from ammonium sulphate. Velthof *et al* (1990) used the wind tunnel method as described by Lockyer (1984) to measure NH_3 emissions from urea and CAN. The wind velocity in the tunnel was adjusted twice a day to the wind velocity in the field at 25 cm, the average height of the tunnel. The tunnels were moved twice a day to minimise deviating conditions inside the tunnel. Mean NH_3 losses over 7 experiments for urea and CAN were 22.6 ± 15.6 and -1.8 ± 6.0% of the applied N. Also the grazing experiments of Jarvis *et al* (1989a,b) and Bussink (1992) indicate that the emissions from the applied AN (CAN) fertiliser were low, the dominant source of NH_3 emissions from pastures is urine voided by the animals.

The emissions (on N-basis) from ammonium nitrate application is expected to be somewhat below half of those of ammonium sulphate on comparable soils. By comparing published data on emissions from these 2 fertilisers the estimate is made that appropriate emission factors for ammonium nitrate are: 3% (Group I), 2% (Group II) and 1% (Group III).

These estimates are within the range of those used by other authors (Table 12 of main text). Further field data on emissions under European conditions would be desirable, especially from the Mediterranean region.

Anhydrous Ammonia

Soil injection with anhydrous ammonia as fertiliser is common in the US where about 35% of the fertiliser N is applied in this manner. However the only western European country where ammonia

injection is used to some extent is Denmark where it accounts for 16% of fertiliser nitrogen usage. In all other parts of Western Europe this application method represents less than 2% of the nitrogen used.

When properly used volatilisation from anhydrous NH_3 injected into the soil can be less than 1% (Denmead *et al*, 1977). Danish results indicate that the loss is usually below 4%. But if the soil is too dry or too wet, emissions increase markedly, to 20% or more (Sommer and Sørensen, 1991). Based on this an emission factor of 4% is used.

Nitrogen Solutions

Nitrogen solutions consist mostly of a mixture of urea and ammonium nitrate, 50% (on N basis) of each. They are common as fertiliser in France (about 22% of the N application), some are used in Germany, Spain and the UK (about 5% of the application), in other countries the use of this fertiliser is comparatively rare.

The composition indicates that an emission factor intermediate between that of urea and ammonium nitrate should be appropriate. The emissions may be reduced by the application form, as the solution should increase the rate of penetration of the nitrogen in the soil, but Al-Kanai *et al* (1991) found that soil water furthers vaporisation of NH_3. Christensen and Sommer (1989) reported that UAN had lower NH_3 loss than urea, while Meyer *et al*, 1961 reported the opposite.

A tentative emission factor of 8% is adopted. The lack of differentiation between soil types reflects the lack of experimental data.

Other Straight Nitrogen

Other straight nitrogen fertilisers will in Europe mainly be nitrates: calcium, potassium and sodium nitrates with no NH_3 to lose. Calcium dicyandiamide, ammonium chloride and ammonium carbonate is so sparsely used as fertiliser in Europe that their contribution to emissions can be discounted. Hence the emission factor 0 for this category is used.

Ammonium Phosphate Nitrogen

Ammonium phosphate nitrogen will either be diammonium phosphate (DAP), with a rather high loss potential (a water solution has pH 7.9) or products principally based on monoammonium phosphate

(MAP), alone or with added ammonium nitrate. These all have less potential for NH_3 loss than DAP.

In both cases the potential for loss is somewhat restricted through soil reactions precipitating NH_4^+ as calcium ammonium phosphate (Larsen and Gunary, 1962). In the IFA statistics the category "ammonium phosphate N" will be mostly DAP, and the category "other NPN" will be mostly be products with much MAP.

With guidance from the results of Whitehead and Raistrick (1990) 5% is used as emission factor for ammonium phosphate N. It seems superfluous to separate between soils in this case as the use of DAP in Greece and Spain is not large.

Other NP-N, NK-N and NPK-N

These are mostly compound fertiliser containing the nitrogen in the form of ammonium nitrate, MAP or both. Hence the same emissions facta as used for ammonium nitrate seems appropriate.

The exception is blends: In this the nitrogen is usually present as DAP or MAP, with some urea (common in the USA, less so in Europe) or ammonium nitrate. Blends are common in the US. But in Europe it is only in Ireland that blends represent a major part of the compound market. In view of this the same emission factors are used as for ammonium nitrate for these categories, except for Ireland where 5% is used due to the common presence of DAP in blends.

A summary of emission factors for important IFA statistical catagories is at Table C.6.

C.2.6.3 Fertiliser Use (Cell N36-42)

The amounts of mineral fertilisers made in individual countries in 1988 are discussed in Chapter 2 and their use is listed in IFA (1992).

NH_3 volatilisation after fertiliser application is calculated as exemplified for urea:

$$R36 = I36 \times M36 \qquad \text{(Eq. C.15)}$$

Table C.6 Emission Factors (%) for Important IFA Statistical Categories (IFA, 1992)

	Ammonium sulphate	Urea	Ammonium nitrate	Anhydrous ammonia	Nitrogen solution	Nitrogen phosphate N	Other straight N	Other NK-N, NPK-N
Austria	5	15	1	-	-	5	0	1
Belgium/ Luxembourg	10	15	2	-	-	5	0	2
Denmark	5	15	1	4	-	5	0	1
Finland	5	15	1	-	-	5	0	1
France	10	15	2	-	8	5	0	2
Germany	5	15	1	-	8	5	0	1
Greece	15	20	3	-	-	5	0	3
Ireland	10	15	2	-	-	5	0	5
Italy	10	15	2	-	-	5	0	2
Netherlands	10	15	2	-	-	5	0	2
Norway	5	15	1	-	-	5	0	1
Portugal	10	15	2	-	-	5	0	2
Spain	15	20	3	-	8	5	0	3
Sweden	5	15	1	-	-	5	0	1
Switzerland	5	15	1	-	-	5	0	1
UK	10	15	2	-	8	5	0	2

C.2.7 EMISSIONS FROM INDUSTRY, CROPS AND MISCELLANEOUS SOURCES (Row 45-47)

C.2.7.1 **Industry** (Cell R45)

The emission from fertiliser production is discussed in Chapter 2 and in Appendix B where details can be found.

C.2.7.2 **Crops** (Cell R46)

Areas are taken from FAO yearbook (1992), where arable land and permanent pastures are listed separately and emissions calculated as 1.5 kg NH_3-N/ha of the combined area, as discussed in the main text (Section 3.4) and, in more detail, by Holtan-Hartwig and Bøckman (1994). The statistics does not split grassland into mown and grazed swards. Hence the combined area has been used, though this may result in some overestimation of emissions, as NH_3 volatilisation from grazing partly include emissions from the grass itself.

C.2.7.3 **Miscellaneous (Cell R47)**

As discussed in Section 3.5 of the main text this is taken as 8% of total emissions.

C.3 NETHERLANDS (Table C.7)

C.3.1 CALCULATION FACTORS

C.3.1.1 Inside Winter and Summer (Column C and D)

Cattle

Cattle > 2 years are assumed to be dairy cows. These are kept indoors during 0.5 years and fed a winter ration. During summer a number of cows are milked indoors, while a smaller number is kept indoors and fed a summer ration (mown grass). For the Netherlands as a whole a period of 0.2 years is assumed.

Yearlings (1-2 years) are inside for approximately 0.5 years and fed a winter ration. During the half of the year they are entirely outside (and the inside summer period is 0 years).

Calves (< 1 years) are inside and fed a winter diet for approximately 0.75 years. During the other part of the year they are entirely outside.

Sheep, Goats and Equine Animals

Sheep and goats are kept inside and are fed a winter diet during approximately 0.2 years. The rest of the year they are outside.

It is assumed that on average equine animals are inside and fed a winter diet during 0.5 years, and are otherwise outside.

C.3.1.2 Nitrogen Excretion in Summer and Winter (Column E)

When cows are housed in the winter, they are often fed maize silage and grass silage. During summer cows mainly graze outdoors on pasture rich in N (fertilised or grass-clover pastures). Only for milking or during the night they are brought inside. Mandersloot (1992) found that the average daily N excretion of cattle is 1.25 (range 1.15-1.50) times higher during summer than during winter.

C.3.2 EMISSION FACTORS FOR ANIMAL HOUSES

C.3.2.1 Animal Houses in Winter and Summer

Cattle

In the Netherlands, the most common animal house type is open housing with a slatted floor. Approximately 70% of all cattle are kept in houses of this type. These animal houses have natural ventilation and it is difficult to measure NH_3 emissions, because the incoming and outgoing airflows are unknown. Those houses fitted with an artificial ventilation are better suited for emission measurements, because air flows are known. Measuring the concentration in the outgoing air is then sufficient to estimate NH_3 emissions.

In 1989 from January to July NH_3 emission was measured in such an artificially ventilated cow house (Oosthoek and Verboon, 1990). The cows in this experiment had an average milk production of about 8100 kg/year. They were fed a diet of 65% grass silage, 35% maize silage and concentrates in winter. During summer the cows were at night in the animal house and fed concentrates and maize silage. They were at pasture during the day. It can be calculated (Mandersloot, 1992) that with this efficient diet the average N excretion/season would be 143 kg/cow/year. For comparison the average N excretion of a Dutch cow was calculated as 134 kg N/year.

The NH_3 emission measurements took place from January to July 1989 while cows are normally kept indoors from November until May. From mid May onwards the cows grazed during the day. The emission data from January to mid April are used to calculate an emission rate/cow for the whole winter period. This gives an average winter emission rate of 0.02825 kg N/cow/day with a variation of less than 10%. From May 19 until July the cows were kept inside 15 hours/day. The average emission was 1.01 kg N/cow/month with a variation of about 20% (Oosthoek *et al*, 1990). This is equivalent to 1.01x24/(15x30)=0.055 kg N/day. The hottest time of the year was not included in these experiments. High temperatures increase NH_3 volatilisation, and also in most countries more N is excreted during summer than during winter because the animals get fresh grass with high N content. Hence the average emission rate is rounded upwards to 0.06 kg/N/day. These values refer to highly productive cows and should be adjusted. It is assumed that the emission factor is linearly related to total N excretions. Hence the emission factor cows, winter (Cell F12) is adjusted as follows:

$$F12 = (0.02825 \times N_{excretion}) / 143 = 0.02647 \qquad \text{(Eq. C.16)}$$

Table C.7: Netherlands 1990

	A	B	C	D	E	F	G	H	I
	Category		Calculation factors			Emission factors			
	Animals	Number (x1000)	Inside winter (y)	Inside summer (y)	N excretion (summer/ winter)	Animal houses winter (kg N/ hd/d)	Animal houses summer (kg N/ hd/d)	Grazing (N loss/ N excreted)	Spreading (N loss/ N applied)
11	Total cattle	4,830							
12	> 2 y	2,171	0.50	0.20	1.25	0.02647	0.05622	0.080	0.285
13	1-2 y	964	0.50	0.00	1.25	0.01719	0.03650	0.080	0.285
14	< 1 y	1,695	0.75	0.00	1.25	0.00711	0.01510	0.080	0.285
16	Total pigs	13,788							
17	Pigs for slaugther	7,746	1.00			0.00680	0.00680		0.285
18	Boars and sows	1,299	1.00			0.01680	0.01680		0.285
20	Total sheep	1,870	0.20	0.00	1.25	0.00672	0.01427	0.046	0.285
22	Total goats	77	0.20	0.00	1.25	0.00672	0.01427	0.046	0.285
24	Equine	185	0.50	0.00	1.25	0.00988	0.02098	0.080	0.285
26	Total poultry	92,765							
27	Laying hens	51,593	1.00			0.00019	0.00019		0.376
28	Table fowl	41,172	1.00			0.00015	0.00015		0.072
30									
34	**Fertilisers**								Emission factor
36	Urea								0.150
37	Ammonium nitrate								0.020
38	Ammonium phoshpate								0.050
39	Ammonium sulphate								0.100
40	Other								0.000
42									
45	**Industry**								
46	**Crops**								
47	**Miscellaneous**								
49									

Table C.7: Netherlands 1990

J	K	L	M	N	O	P	Q	R	S	T
N Excretion					NH_3-N emissions					
Total (kg N/ hd/y)	Within animal house (kg N/ hd/y)	Outside animal house (kg N/ hd/y)	Total (kt N)	Total in slurry (kt N)	Animal houses (kt N)	Surface spreading (kt N)	Grazing (kt N)	Total (kt N)	% of N excreted	% per category
										46.8
134	89.33	44.67	291	175	19.4	49.7	7.8	76.9	26.4	
87	38.67	48.33	84	34	3.0	9.8	3.7	16.5	19.7	
36	25.41	10.59	61	40	3.3	11.3	1.4	16.1	26.3	
										26.5
13.6	13.60	0.00	105	86	19.2	24.5		43.8	41.5	
33.6	33.60	0.00	44	36	8.0	10.2		18.1	41.5	
34	5.67	28.33	64	10	1.0	2.7	2.4	6.2	9.7	2.6
34	5.67	28.33	3	0	0.0	0.1	0.1	0.3	9.7	0.1
50	22.22	27.78	9	4	0.3	1.1	0.4	1.8	19.8	0.8
										8.8
0.766	0.766	0.00	40	36	3.6	13.5		17.1	43.2	
0.455	0.455	0.00	19	16	2.3	1.2		3.4	18.4	
		Subtotal	**718**	**437**	**60**	**124**	**16**	**200**	**28**	**85.6**
			Fertiliser use (kt N)					NH_3-N losses (kt N)		
				2.0				0.3		
				400.0				8.0		
				1.0				0.1		
				1.0				0.1		
				5.0				0.0		
			Subtotal	**409.0**				**8.5**	**2.1**	**3.6**
								3.6		1.6
								3.0		1.3
								18.7		8.0
							Total	**234.0**		**100.0**

Where $N_{excretion}$ is the total N excretion (Cell J12).

Similarly, the emission factor for summer (Cell G12) becomes:

$$G12 = (0.06 \times N_{excretion}) / 143 = 0.05622 \qquad \text{(Eq. C.17)}$$

This principle is also used for calculations of emission factors for younger animals, with $N_{excretion}$ = 87 kg N/year for younger cattle (1-2 years) (Cell J13) and $N_{excretion}$ = 36 kg N/year for calves (Cell J14).

The animal house emissions include that from the slurry stored in the animal house (Section 2.3.1). Dutch research (Monteny, 1991) indicates that emission from animal houses with slatted floors is somewhat higher than from houses with floors of concrete (where the cattle is kept on straw), but the same emission factors are used for all animal houses for reasons of simplicity.

Pigs

Experiments in the Netherlands with pigs for slaughter showed similar emissions of NH_3-N for 3 animal house types (Oosthoek *et al*, 1990). The average emission in these experiments was 3.0 kg NH_3/pig/year. This is equivalent to a daily emission rate in pig houses of 0.0068 kg N/hd/day.

Animal house measurements for sows are not available, so an emission rate has to be estimated. The animal house types for sows may be somewhat different to those for pigs for slaughter. This can affect the emission rate, but is not taken into account as there are not enough data available. De Winkel (1988) has calculated that the N emission of sows (including the piglets) should be 4 times that of pigs for slaughter. This seems somewhat too high, because it is expected that NH_3 emission is linearly related to N excretion which is 2.47 times that of pigs for slaughter. Therefore it is assumed that the emission factor in a sow house is:

$$\frac{(N_{excretion\ of\ sows})}{(N_{excretion\ of\ pigs})} \times 0.0068 \text{ kg N/hd/d} \qquad \text{(Eq. C.18)}$$

The same emission factors are used for summer and winter, because the emission data of Oosthoek *et al* (1990) were based on a whole year.

Sheep, Goats and Equine Animals

For these categories no Dutch data are available. The emission factors in Cell F20-24 are calculated from the formula used for cows: stabled in winter because total NH_3 losses (in % of N) from stabled animals and handling of their manure tend to be similar both for animals kept on concrete and straw, and on slatted floors (Monteny, 1991; Section C 3.2.1). The $N_{excretion}$ for sheep, goats and horses are 34, 34 and 50 kg N/hd/year as described in Section C.2.4.1.

Poultry

Laying hens

Calculations show that total emissions from the point of manure production up to and including slurry spreading (or composting) vary between three common shed types in the Netherlands: (i) sheds with open storage below the battery (ii) manure conveyor bettery with dried manure removal or (ii) manure conveyor battery with slurry removal. Natural as well as mechanical ventilation is common. Three calculations based on measurements plus a calculation based on standard values are shown below.

(i) Open Storage Below the Battery

The N emission from a shed with open storage below the battery is 68g per hen (Kroodsma, 1989) per year. The normal practice for this type of shed is for slurry to be pumped out and spread as soon as the pit is full.

Emission factors from three spreading experiments with poultry slurry containing about 10kg N/t were 29.1% and 38.2% and 45.4% of the N applied (Pain and Klarenbeek, 1988). On this basis it is calculated that the average N emission is 37.6% of the N applied. If an average excretion of 766g N/hen/year is assumed (Section C.2.4.1) then total losses are 68+0.376x(766-68)=330g N/hen/year.

(ii) Manure Conveyor Battery with Dry Manure Removal

The average NH_3-N emission during a whole year in this type of shed has been measured at 26g/hen (Kroodsma, 1989). However, most of the ammonia emission occurs outside the shed during manure processing. Experiments on composting are depicted in Table C.8.

Table C.8 NH_3-N Emission from Composting Laying Hen Manure (Kroodsma, 1989)

Experiment (No.)	Dry matter (%)	NH_3-N loss (g N/hen/y)	Dry matter NH_3-N	Dry matter after composting (%)
1	34.9	179.8	6,274	48.1
2	51.2	114.0	5,836	62.1
3	54.1	70.4	3,827	76.3
4	40.3	150.2	6,057	67.9

Low dry matter content gives high emissions. Losses are low when dry matter content is above 70%. In Kroodsma's (1989) measurements the dry matter content was 47.3%. Under these conditions emissions during composting are about 130 g N/hen/year. This emission must be added to the loss from the stable, giving a combined emission of 156g NH_3-N/hen/year. Emission from dry poultry manure was 6.5% (Pain and Klarenbeek, 1988) of the total N. Total loss becomes now 156+0.065x(766-156)=196g NH_3-N/hen/year.

(iii) Manure Conveyor Battery with Manure Removal

The average NH_3-N emission during a whole year in this type of shed has been measured at 28g/hen (Kroodsma, 1989). In Kroodsma's (1989) measurements the dry matter content was 25.8%. If this manure is composted then emissions during composting may be as high as 300 g N/hen/year. Emission from dry poultry manure was 6.5% (Pain and Klarenbeek, 1988) of the total N. Total emission then becomes 328+0.065 x (766-328) = 356 g NH_3-N/hen/year. If the manure of 25.8% dry matter is spread then total losses amount to 28+0.40x(766-28) = 295 g N/hen/year.

(iv) Calculation from Standard Values

A light hen produced about 720g N in excreta annually and a middle heavy hen approximately 812g (Coppoolse *et al*, 1990). The 'Handboek voor Rundveehouderij' states that a hen produces 63kg slurry per year with 10.6g N/kg (Pelser, 1988). This would mean that shed losses vary between 52.2 and 144.2 (720 or (812-10.6x63))g N/hen/year. This agrees reasonably well with the measured results of Kroodsma (68g).

The 'Handboek voor de Rundveehouderij' further states that a hen produces 18kg dry manure per year at 24.3 g N/kg. If an average excretion of 766 g N/hen/year is assumed (Section 2.4.1), then the shed and storage losses are 766-24.3x18 = 328.6 g N/hen/year. Total emission including spreading then becomes 328.6+0.65x(766-328.6) = 357 g N/hen/year.

The four examples show only minor differences, except for (ii). Therefore example (i): Open storage below the battery, is used throughout for the calculations. Thus emissions are taken as 68 g N/hen/year giving $(68/365)x10^{-3}$ = 0.0001863 kg N/hen/day as emission factors in Cells F27 and G27.

Table fowl

Broilers are generally kept on a saw dust floor. Kroodsma (1989) used 6 measuring periods/year in an animal house with an unisolated floor and found a total loss of 37.9 g NH_3-N/year broiler. In an animal house with an isolated floor he measured a total loss of 32.9 g NH_3-N/broiler/year. In the calculations a value of 37.9 is used. This is equivalent to a emission of 0.1038 g NH_3-N/broiler/day. Storage losses must always be included.

For broilers, the litter in the animal house is removed after every cycle. Broiler litter will usually be composted outdoors. Results from 6 composting periods of 7 days gave an average emission of 2.73 g (varying between 1.25 and 5.75 g) NH_3-N/broiler (Kroodsma, 1989). This gives an emission of 16.4 g NH_3-N/year or 0.0447 g NH_3-N/day. Composting losses were small compared to those from laying hens, because the dry matter content of the broiler litter before composting was high; approximately 60% for broiler manure and only 45% for battery manure. Combined emissions are thus 0.1038 + 0.0449 = 0.1486 g N/broiler/day. Hence the factors in Cells F28 and G 28 are 0.00015 kg N/broiler/day.

C.3.2.2 **Spreading** (Column I)

Cattle and Pigs

A number of emission experiments has been carried out (Bruins and Huijsmans, 1989; Van der Molen *et al*, 1989; Bussink and Klarenbeek, 1990; Huijsmans and Bussink, 1990). The measured results of individual experiments showed large differences, varying from 20 to 100% of the NH_3-N applied, but averaged results showed only minor differences between surface spreading on grassland and that on arable land. There was also little difference between pig and cattle slurry. For this reason and because it is not known how much slurry is used on grassland and how much

on arable land, the average of 16 experiments up to 1990 is used for grassland as well as for arable land. This average emission was 28.5% of the N applied and is used in Cell I12-18 as a calculated average for all cattle and pigs.

The wide range of results reported on NH_3 emissions following manure spreading and the many factors that influence emissions (discussed in Section 3.2.4 of the main text) may make the use of a calculated average NH_3 emission following spreading seem a simplistic approach. However, it seems at present the only practical approach, as sufficient data for a more detailed calculation are not available.

Sheep, Goats and Equine Animals

The emission factors for sheep, goats and equine animals are assumed to be similar to those for cattle and pigs.

Poultry

Laying hens

Emissions from the point of manure production up to and including slurry spreading seem to be independent of the animal house type (Section 3.2.4). It is assumed therefore that all laying hen manure is produced in animal houses with open storage below the battery. This gives an average NH_3-N spreading emission of 37.6% of the N applied (Section 3.2.4, example (i)). Thus factor I27 is 0.376.

Table fowl

NH_3 emissions after spreading of composted broiler litter will be low due to the high dry matter content and the low NH_4^+-N content. In a single wind tunnel experiment a loss of 7.2% of the N applied was measured for broiler litter (Pain and Klarenbeek, 1988). Dry matter contents were respectively 75% and 61%. Other emission data are not available. An emission factor of 0.072 for I28 is used in the spreadsheet.

C.4 GERMANY (Table C.9)

C.4.1 CATEGORY AND NUMBER OF ANIMALS (Column A and B)

There have been rapid changes in German agriculture following the re-unification. The number of animals have been reduced, especially in East Germany (former German Democratic Republic area).

The numbers of poultry have been taken from national statistics (ZMP, 1993).

C.4.2 CALCULATION FACTORS (Column C, D and E)

Conditions in animal husbandry are sufficiently similar between Germany and the Netherlands to permit the use of Dutch calculation factors.

C.4.3 EMISSION FACTORS

C.4.3.1 Animal Houses in Winter and Summer (Column F and G)

Oldenburg (1989) has described measurements of NH_3 emission from naturally ventilated livestock buildings in the northern part of Germany (Schleswig-Holstein and Nord-Niedersachsen) between autumn 1986 and spring 1987. NH_3 emission was measured in different types of cattle, pig and poultry houses. Emission factors for animal houses can be calculated from the results:

Cattle

The average emission factor for cattle sheds, calculated from the data of Oldenburg (1989), is only approximately 20% of the value obtained in experiments in the Netherlands (Oosthoek *et al*, 1990, Section 3.2.1). The large difference is most probably due to experimental design and not to differences in animal house management and/or slurry composition. The measurements of Oldenburg took place in a naturally ventilated cow shed, whereas the Dutch results were obtained in an artificially ventilated animal house. As Jarvis and Pain (1990) have shown, it is very difficult to measure accurately the strongly fluctuating airflows into and out of a naturally ventilated animal house. Artificially ventilated animal houses allow a much more accurate measurement of incoming and outgoing airflows. At present, only artificially ventilated cow houses give reliable measurement results.

Table C.9: Germany 1990

	A	B	C	D	E	F	G	H	I
	Category		Calculation factors			Emission factors			
	Animals	Number of animals (x1000)	Inside winter (y)	Inside summer (y)	N excretion ratio summer/ winter	Animal houses winter (kg N/ hd/d)	Animal houses summer (kg N/ hd/d)	Grazing, N loss/N excreted	Spreading N loss/N applied
11	Total cattle	19,488							
12	> 2 y	8,044	0.50	0.20	1.25	0.04255	0.06889	0.080	0.220
13	1-2 y	4,731	0.50	0.00	1.25	0.03202	0.05183	0.080	0.220
14	< 1 y	6,713	0.75	0.00	1.25	0.01438	0.02310	0.080	0.220
16	Total pigs	30,819							
17	Pigs for slaugther	20,434	1.00			0.00716	0.00716		0.140
18	Boars and sows	2,906	1.00			0.01846	0.01846		0.140
20	Total sheep	3,239	0.20	0.00	1.25	0.00395	0.00839	0.046	0.220
22	Total goats	90	0.20	0.00	1.25	0.00395	0.00839	0.046	0.220
24	Equine	484	0.50	0.00	1.25	0.00988	0.02098	0.080	0.220
26	Total poultry	106,055							
27	Laying hens	53,652	1.00			0.00030	0.00030		0.376
28	Table fowl	52,403	1.00			0.00039	0.00039		0.072
30									
34	**Fertilisers**								Emission factor
36	Urea								0.150
37	Ammonium nitrate								0.010
38	Ammonium phosphate								0.050
39	Ammonium sulphate								0.050
40	Other								0.080
42									
45	**Industry**								
46	**Crops**								
47	**Miscellaneous**								
49									

Table C.9: Germany 1990

J	K	L	M	N	O	P	Q	R	S	T
Excretion of N					NH_3-N emissions					
Total (kg N/ hd/y)	Within animal house (kg N/ hd/y)	Outside animal house (kg N/ hd/y)	Total (kt N)	Total in slurry (kt N)	Animal houses (kt N)	Surface spreading (kt N)	Grazing (kt N)	Total (kt N)	% of N excreted	% per category
										53.3
101	67.33	33.67	812	439	102.9	96.5	21.7	221.1	27.2	
76	33.78	42.22	360	132	27.6	29.1	16.0	72.7	20.2	
33	23.29	9.71	222	130	26.4	28.6	5.2	60.2	27.2	
										17.0
12.8	12.80	0.00	262	208	53.4	29.1		82.5	31.6	
33	33.00	0.00	96	76	19.6	10.7		30.3	31.6	
20	3.33	16.67	65	10	1.1	2.1	2.5	5.7	8.8	0.9
20	3.33	16.67	2	0	0.0	0.1	0.1	0.2	8.8	0.0
50	22.22	27.78	24	10	0.9	2.2	1.1	4.2	17.2	0.6
										4.1
0.766	0.766	0.00	41	35	5.9	13.2		19.1	46.5	
0.348	0.348	0.00	18	11	7.5	0.8		8.2	45.2	
		Subtotal	**1,901**	**1,051**	**245**	**212**	**46**	**504**	**27**	**75.9**
			Fertiliser use (kt N)				NH_3-N losses (kt N)			
			314.5					47.2		
			1,636.1					16.4		
			0.0					0.0		
			187.6					9.4		
			69.0					5.5		
		Subtotal	**2,207.2**					78.4	3.6	11.8
								1.5		0.2
								27.1		4.1
								53.1		8.0
							Total	**664.3**		**100.0**

Oldenburg (1989) also derived regression equations relating the temperature of air entering the animal house and NH_3 emission for cattle houses. As indicated, the absolute values obtained by Oldenburg (1989) for cattle sheds are questionable, due to the method of ventilation. However, the effect of temperature on NH_3 emission from animal houses is probably not affected. The regression equation for cattle sheds as NH_3 emission in mg NH_3/hour/[large animal unit] is :

$$226 + 9.7t \qquad \text{(Eq. C.19)}$$

where r = 0.41, t in °C, range of t: -7°C to 20°C.

Other Dutch results (unpublished) as well as consideration of vapourisation dependency on temperature indicate that the emission increase with increasing temperature, though the spread of data makes a correlation weak in this instance.

As there is not much difference between the average year temperature for Netherlands and Germany, a temperature correction is omitted.

In conclusion, the Dutch method for calculation of emission factors was used (Section C.3.2.1).

Manure Storage

According to Sciborski and Zimmermann (1990), farmyard manure is still very important in the eastern part of Germany; 65% of the cattle are kept on litter. However, combined NH_3 emissions are similar irrespective of manure collection system (Isermann, 1990a).

In Germany, manure is generally stored outside the animal house. Storage losses are taken into account as described in Section C.2.3.1. Isermann (1990a) estimates that approximately 10% of the total N in storage gets lost as NH_3. This is done in the spreadsheet through the calculation for winter:

$$\frac{0.02825 \times J12}{143} + \frac{J12 \times C12}{C12 + E12 \times (1 - C12)} - \frac{0.02825 \times J12 \times C12 \times 365 \times 0.1}{143 \times 12 \times 365} \qquad \text{(Eq. C.20)}$$

which can be simplified to:

$$\frac{0.9 \times 0.02825 \times N_{excretion}}{143} + \frac{0.1 \times N_{excretion}}{365 \times (C12 + E12 \times (1 - C12))} \qquad \text{(Eq. C.21)}$$

and for summer:

$$\frac{0.06 \times J12}{143} + \frac{J12 \times E12 \times (1-C12)}{C12 + E12 \times (1-C12)} - \frac{0.02825 \times J12}{143} \times \frac{(1-C12) \times 365 \times 0.1}{(1-C12) \times 365} \qquad \text{(Eq. C.22)}$$

which gives:

$$\frac{0.9 \times 0.06 \times N_{excretion}}{143} + \frac{0.1 \times N_{excretion} \times E12}{365 \times (C12 + E12 \times (1-C12))} \qquad \text{(Eq. C.23)}$$

Total losses/day in winter and summer for cows, yearlings and calves become now respectively: 0.04255; 0.06889 and 0.03202; 0.05183 and 0.01438; 0.02310 kg N/hd/day.

Pigs

Pigs for slaughter (Cell F17-G17)

NH_3 emissions were determined in 47 pig houses without litter and in 15 pig houses with litter (Oldenburg, 1989). The pig houses were artificially ventilated. In the first group of animal houses, individual animal weights ranged from 22 to 100 kg, with an average of approximately 60 kg. The total weight of animals in each house ranged from 2,300 to 26,000 kg. Correction factors for variations in NH_3 emission during the day and the year were used to calculate average NH_3 volatilisation from the animal houses. In the calculations an average year temperature of 7.9 °C is used. The type of floor strongly influenced NH_3 volatilisation from animal houses without litter. Of the examined animal houses, 42 had a partly slatted floor and 5 a slatted floor. Average N losses through NH_3 volatilisation were 1.35 and 2.38 g NH_3/hour/[large animal unit] (= 500 kg live weight), for pig houses with a partly slatted and a slatted floor respectively. Using the average weight/hd, it can be calculated that NH_3 emissions were 0.00320 and 0.00564 kg NH_3-N/hd/day, for the 2 pig house types, respectively. In the animal houses with litter body weight ranged from 30 to 110 kg/hd and the total weight of animals from 2,150 to 14,650 kg. House-average NH_3 volatilisation was 2.15 g NH_3/hour/[large animal unit] or 0.00595 kg NH_3-N/hd/day, assuming an average animal body weight of 70 kg.

This result (0.00595 kg NH_3-N/hd/day) as emission factor from pigs on litter is used in subsequent calculations for the UK and Denmark.

If it is assumed that the animal houses and their relative proportion were representative for Germany, average NH_3 emission from houses for fattening pigs is: (0.00320x42 + 0.00564x5 +

0.00595x15)/(42+5+15) = 0.00406 kg NH_3-N/hd/day for (Cell F17 and G17) with an estimated range of 0.002 to 0.008 kg NH_3-N/hd/day. This is approximately 40% lower than in the Netherlands. The difference can be ascribed to differences in animal house types and manure collection methods, as straw is more commonly used in Germany than in the Netherlands.

Bresk and Stolpe (1990) found somewhat higher emissions (0.0067 and 0.0137 kg N/hd/day) for pigs for slaughter and for sow houses in former GDR. Because animal populations and emissions in that region are being reduced the data from Oldenburg are used as basis for the calculations.

It must be emphasised that this emission factor for pig houses is calculated for an average year temperature of 7.9 °C. Other data of Oldenburg (1989) show that the NH_3 emission from pig houses is clearly correlated with temperature of the air entering the animal house, so that NH_3 emission rates during summer will be greater than those during winter. He derived a regression equation between the temperature of the air entering a fattening pig house without litter and NH_3 emission in mg NH_3/hour/[large animal unit]:

$$1{,}271 + 64.9t \qquad \text{(Eq. C.24)}$$

Where:

r = 0.86

t = temperature (°C), range -7°C to 17°C.

NH_3 emission rates during summer are thus higher than during winter. Seasonal variations are not included in present calculations. However, temperature corrections are made for the emissions from mediterranean countries, see Italy.

Manure Storage

As for cattle, storage losses should be included since 54% of the pigs are kept on litter (Sciborski and Zimmerman, 1990). Including storage losses, total daily loss rate amounts to :

$$0.00406 + \frac{((N_{excretion,\,pigs}) - 0.00406 \times 365) \times 0.10}{365} = 0.00716\,\text{kg } NH_3\text{-N/hd/d} \qquad \text{(Eq. C.25)}$$

Boars and Sows

Emission factors animal houses for boars and sow houses are calculated by linear extrapolation of the factor for pigs for slaughter and manure production/head (Column J):

$$\frac{J18 \times 0.00716}{J17} = \frac{33 \times 0.00716}{12.8} = 0.01846 \text{ kg } NH_3\text{- N/hd/d} \qquad \text{(Eq. C.26)}$$

Sheep, Goats and Equine Animals

The calculation procedure as for cattle is used, corrected for N excretion. Virtually all of the sheep are kept on litter.

For Germany the standard value for N excretion of 20 kg N/hd/year is used (J20), while in the Netherlands with greater N intensity 34 kg is used. The emission factor for Germany is thus calculated as: 0.02825 x 20/143 = 0.00395. During summer sheep and goats are outside, so a summer emission factor from animal houses is not appropriate.

Poultry

Laying hens

NH_3 volatilisation was determined in 37 houses for laying hens divided into 3 groups (Oldenburg, 1989). The animal houses were artificially ventilated. Group I. 22 battery hen houses with both brown and white laying hens. The average weights/hd were 2.3 and 1.7 kg for brown and white hens respectively. This is the most common type of hen house used for egg production in West Germany. Two houses for breeding hens with an average weight/hd of 0.8 kg were examined. The total weight of hens per house was 1,200 to 26,000 kg. Group II: 6 houses with laying hens kept on the floor, a type which is not common in the production of eggs for consumption but more in the production of brood eggs. All 6 hen houses had litter and, therefore, a large part of the manure was dry. The average weight/hd was 1.9 to 3.3 kg and the total weight of hens was 4,100 to 18,600 kg/ house. Group III: 9 breeding houses in which the birds were kept on the floor, with an average weight/hd of 0.95 to 1.3 kg. The birds are kept in this type of house for approximately 6 months up to the reproductive age. Oldenburg (1989) used correction factors for variation of NH_3 volatilisation during the day and the year to calculate average NH_3 emissions from the 3 types of hen houses. The average emissions of NH_3 were 2.00, 7.80 and 7.64 g NH_3/hour/[large animal unit] for the 3 house types, respectively. Using an average weight/hd of 1.89, 2.60 and 1.13 kg,

respectively, average NH_3 emissions for the 3 types of house were 0.00015, 0.00080 and 0.00034 kg NH_3-N/hd/day. If it is assumed that the animal houses examined are representative for West Germany, the average NH_3 emission from laying hen houses is:

$$\frac{(22 \times 0.00015) + (6 \times 0.00080) + (9 \times 0.00034)}{(22 + 6 + 9)} = 0.00030 \text{ kg } NH_3\text{-N /hd/d} \qquad \text{(Eq. C.27)}$$

(factor F27 and G27) with an estimated range of 0.00015 to 0.0006 kg NH_3-N/hd/day.

The average emission factor for poultry houses is calculated for an average year temperature of 7.9 °C. Oldenburg (1989) showed, however, that NH_3 emission from poultry houses increases with increasing temperature of the air entering the house. He derived a regression equation between the temperature of air entering a laying hen house with batteries and NH_3 emission in mg NH_3/[large animal unit]/h:

$$1{,}219 + 77.3t \qquad \text{(Eq. C.28)}$$

Where:

r = 0.72

t in °C, range of t: -6°C to 19°C).

NH_3 emission rates during summer are thus much higher than during winter. There will thus be seasonal variations, with greater emissions in the summer than during the winter. This has not been taken into consideration, but a general temperature correction has been made for the mediterranean countries, see Italy.

Table Fowl

NH_3 volatilisation for broilers was determined in the winter of 1987 in 3 deep litter hen houses (artificially ventilated) in the district of Cuxhaven. Measurement were made after 7, 14, 20, 28 and 35 days (Oldenburg, 1989). During fattening, weight/hd increased rapidly as did NH_3 loss/hd and total NH_3 emission from the animal house. The numbers of animals in the 3 houses examined were 13,700, 13,800 and 28,500. The weight at the end of the fattening period was 1400 g/hd. Annex 10 of Oldenburg (1989) shows the weight/hd and NH_3 emission in g NH_3/[large animal unit]/h for all 3 houses at 5 times during the fattening period. From these data the average NH_3 emission/hd/day was calculated. This was 0.00035 kg NH_3-N/hd/day with an estimated range of 0.00020 to 0.00050

kg NH_3-N/hd/day. As shown for the Netherlands (Section C.3.2.4) approximately 0.00004 kg N/hd/day volatilises during storage (composting). This amount has to be added to the daily emissions from the animal house, giving a NH_3-N loss of 0.00039 kg/hd/day.

C.4.3.2 **Spreading** (Column H)

Cattle

Isermann (1990a) summarised results of experiments on grass and arable land in which N losses through NH_3 volatilisation after spreading of slurry were measured. Most of the data are related to arable land. There were no clear systematic differences between NH_3 emissions from grassland and arable land, and therefore an overall estimate is made for the emission factor for spreading of cattle slurry in FRG. For this purpose, only data of West German authors are used, namely Holzer *et al* (1988); Döhler and Aldag (1989); Döhler *et al* (1987); Amberger (1989, 1990); Amberger *et al* (1987); Huber and Amberger (1990); Rank *et al* (1988) and Horlacher and Marschner (1990). These authors measured NH_3 volatilisation by several methods, including enclosures in laboratory and field, wind tunnel systems, micrometeorological methods and calculations from models using experimentally derived data. The average N loss through NH_3 volatilisation was 43% of the applied NH_3-N (n=55 and standard deviation = 18). If it is assumed that the NH_3-N content of cattle slurry is approximately 50% of the total N (Amberger *et al*, 1987), the emission factor for spreading of cattle slurry in FRG is 22% of the N applied. Thus factor I11 - I13 is 0.22.

Pigs

The emission factor for spreading of pig slurry is calculated in the same way and using the same table of Isermann (1990a) as is used for cattle slurry. Average N loss through NH_3 volatilisation was 20% of the applied NH_3-N (n=8 and standard deviation 12). Assuming that the NH_3-N content of pig slurry is 70% of the total N (Amberger *et al*, 1987), the emission factor for spreading of pig slurry in FRG is 14% of the N applied. It is reasonable to assume a somewhat lower emission of NH_3 from pig slurry application in Germany than in the Netherlands (where the average loss was 28.5% of the N). This because the pig slurry used in the experiments had a low dry matter content, only approximately 1%. This will be associated with a low NH_4^+ concentration and so with a low volatilisation rate. Further, pig slurry with a low dry matter content infiltrates more easily into the soil reducing NH_3 volatilisation further. In conclusion factor 0.14 is used for I16 and 17.

Sheep, Goats, Equine Animals and Poultry

German emission factor for spreading of cattle slurry (0.22) is also used for the sheep, goats and equine categories. The Dutch emission factor 0.40 and 0.72 are used for emissions from spreading of manure from hens and broilers.

C.5 UNITED KINGDOM (Table C.10)

C.5.1 CATEGORY AND NUMBER OF ANIMALS (Column A and B)

A substantial number of horses are located at riding establishments that are not included in agricultural statistics. British Horse Society (1988) estimated the horse and pony population of Great Britain as close to 550.000.

C.5.2 CALCULATION FACTORS

C.5.2.1 Inside Winter and Summer (Column C and D)

Cattle

In the UK most cattle are housed during the winter for 180-200 days (0.5 years). In the summer dairy cows are in the shed for a few hours each day to be milked. This gives a factor 0.1 years in Cell D12.

Sheep, Goats and Equine Animals

Sheep are housed for almost 1 month (0.08 years). This factor is also assigned to goats.

Equine animals are usually housed during winter for 180-200 days (0.5 years). During summer they are mostly housed during the night (0.25 years).

C.5.2.2 Nitrogen Excretion in Summer and Winter (Column E)

The Dutch factor is used (Section C.3.1.2).

C.5.3 EMISSION FACTORS

C.5.3.1 Animal Houses in Winter and Summer (Column F and G)

Cattle

Ryden *et al* (1987) estimated the NH_3 emission from a house containing 70 cows by measurement of NH_3 concentration and rates of air flow (natural ventilation) in the building. The average NH_3 emission was 1.87 kg N/day ranging from 0.3 to 3.8 kg N/day, which corresponds to an average

Table C.10: United Kingdom 1990

	A	B	C	D	E	F	G	H	I
	Category		Calculation factors			Emission factors			
	Animals	Number of animals (x1000)	Inside winter ration (y)	Inside summer (y)	N excretion ratio summer/ winter	Animal houses winter (kg N/ hd/d)	Animal houses summer (kg N/ hd/d)	Grazing, N loss/N excreted	Spreading N loss/N applied
11	Total cattle	11,843							
12	> 2 y	5,221	0.50	0.10	1.25	0.05140	0.08321	0.080	0.285
13	1y< <2 y	3,257	0.50	0.00	1.25	0.03666	0.05934	0.080	0.285
14	< 1 y	3,365	0.75	0.00	1.25	0.01568	0.02520	0.080	0.285
16	Total pigs	7,380							
17	Pigs for slaugther	4,569	1.00			0.00907	0.00907		0.054
18	Boars and sows	816	1.00			0.02338	0.02338		0.054
20	Total sheep	30,147	0.08	0.00	1.25	0.00454	0.00965	0.046	0.285
22	Total goats	113	0.08	0.00	1.25	0.00454	0.00965	0.046	0.285
24	Equine	550	0.50	0.00	1.25	0.00988	0.02098	0.080	0.285
26	Total poultry	106,125							
27	Laying hens	33,225	1.00			0.00019	0.00019		0.376
28	Table fowl	72,900	1.00			0.00015	0.00015		0.072
30									
34	**Fertilisers**								Emission factor
36	Urea								0.150
37	Ammonium nitrate								0.020
38	Ammonium phosphate								0.050
39	Ammonium sulphate								0.100
40	Other								0.080
42									
45	**Industry**								
46	**Crops**								
47	**Miscellaneous**								
49									

Table C.10: United Kingdom 1990 (cont.)

J	K	L	M	N	O	P	Q	R	S	T
N Excretion					NH_3-N emissions					
Total (kg N/ hd/y)	Within animal house (kg N/ hd/y)	Outside animal house (kg N/ hd/y)	Total (kt N)	Total in slurry (kt N)	Animal houses (kt N)	Surface spreading (kt N)	Grazing (kt N)	Total (kt N)	% of N excreted	% per category
										55.5
122	67.78	54.22	637	289	64.8	82.4	22.6	169.9	26.7	
87	38.67	48.33	283	104	21.8	29.7	12.6	64.1	22.6	
36	25.41	10.59	121	71	14.4	20.3	2.9	37.6	31.0	
										5.2
12.8	12.80	0.00	58	43	15.1	2.3		17.5	29.9	
33	33.00	0.00	27	20	7.0	1.1		8.0	29.9	
23	1.50	21.50	693	40	5.4	11.3	29.8	46.5	6.7	9.5
23	1.50	21.50	3	0	0.0	0.0	0.1	0.2	6.7	0.0
50	22.22	27.78	28	11	1.0	3.2	1.2	5.4	19.8	1.1
										3.4
0.766	0.766	0.00	25	23	2.3	8.7		11.0	43.2	
0.348	0.348	0.00	25	21	4.0	1.5		5.5	21.8	
		Subtotal	**1,901**	**623**	**136**	**161**	**69**	**366**	**19**	**74.8**
			Fertiliser use (kt N)					NH_3-N losses (kt N)		
			150.0					22.5		
			1,352.0					27.0		
			0.0					0.0		
			0.0					0.0		
			80.0					6.4		
			Subtotal 1,582.50					**55.9**	**3.5**	**11.4**
								1.4		0.3
								26.9		5.5
								39.1		8.0
							Total	**489.0**		**100.0**

emission of 0.027 kg N/hd/day. This agrees very well with the values obtained in the Netherlands. Hence, the Dutch emission factors are used for the UK for all animal categories, weighted for N excretion. Generally, manure or slurry is stored outside the animal house. Therefore, we have to include storage losses (Section C.4.3.1, Germany).

Pigs

Pigs for slaughter (Cell F17-G17)

Pigs for slaughter are often housed in mechanically ventilated buildings. Approximately half of them are on straw and the rest on slurry systems. No UK emission factors are available. The German emission factor for litter was 0.00595 kg N/hd/day. The Dutch emission factor for slurry systems was 0.00680 kg N/hd/day, but this should be corrected for the high N excretion of pigs in the Netherlands. On this basis we assume (0.00595 + 0.0068 12.8/13.6)/2 = 0.00618 kg N/hd/day as emission factor.

When manure storage losses are included as for cattle in Germany (Section C.4.3.1), total daily loss rate amounts to 0.00907 kg N/hd/day.

Boars and Sows (Cell F18-G18)

Emission factors for boar and sow houses are calculated by linear extrapolation as for Germany (Section C.4.3.1).

Poultry

As in the Netherlands laying hens are mostly kept in battery cages and produce thick slurry. Therefore the Dutch emission factor of 0.00019 kg N/hd/day is used.

Broilers are kept on deep litter in mechanically ventilated buildings. Because this is in essence the same as in the Netherlands the Dutch animal house emission factor is used for the UK.

C.5.3.2 **Spreading** (Column I)

Cattle

Studies of Pain *et al* (1990); Pain and Thompson (1989); Ryden *et al* (1987); Stevens and Logan (1987) and Thompson *et al* (1987) showed that the levels of NH_3 volatilisation from surface applied cattle slurry in the UK were in the range of those found in the Netherlands. Therefore, for the UK the same emission factor for spreading of cattle slurry is used as for the Netherlands, namely 28.5%. Data from Canada (Beauchamp *et al*, 1982), the Netherlands, Germany and the UK show that N losses through NH_3 volatilisation from surface applied cattle slurry may range from 10% to more than 50% of the total N applied.

Pigs

Some Anglo-Dutch experiments, using micrometeorological methods, showed much larger N losses through NH_3 volatilisation from pig slurry in the Netherlands than in the UK, despite the much higher slurry-N application rates in the UK (Pain *et al* 1989; Pain and Thompson, 1989). This was because of the 3-4 times higher total solids content of pig slurry in the Netherlands compared to that in the UK. A low dry matter content and thus a low NH_4^+ concentration in slurry results in a low volatilisation rate. Further, pig slurry with a low dry-matter content infiltrates the soil more easily and so NH_3 volatilisation is less. The measured NH_3 volatilisation from pig slurry in the UK was 4.9% and 5.8% of the total N applied, at application rates of 260 and 540 kg N/ha, respectively. Similar results were obtained by Hoff *et al* (1981) in experiments in the USA, using pig slurry with a comparable composition to that in the British experiment. The average emission factor for spreading of pig slurry in West Germany, however, is higher than would be indicated by the British experiment, despite the low dry matter content of pig slurry (Section 4.3.2).

In the spreadsheet, 0.00535 is used as the emission factor for spreading of pig slurry in the UK. This is based on only two closely similar results of one experiment and may not be representative. Jarvis and Pain (1990) used the same emission factor (0.183) as for cattle slurry in their estimates. However, the use of observed results seemed preferable over the use of assumptions. Data from Germany show that NH_3 emission from pig slurry with a low dry matter content may range from less than 5 to more than 20% of the total N applied.

Sheep, Goats, Equine Animals and Poultry

The Dutch emission factors for spreading are used for manures from the categories sheep, goats, equine animals and poultry.

C.6 IRELAND (Table C.11)

C.6.1 CATEGORY AND NUMBER OF ANIMALS (Column B)

C.6.2 CALCULATION FACTORS

C.6.2.1 Inside Winter and Summer (Column C and D)

Cattle

It is assumed that all cattle > 1 years are stabled in the winter for approximately 135 days (0.37 years). For calves 0.75 years is used as for the Netherlands. During summer the dairy cows are only in the animal house during milking time. This corresponds with a period of 7/12 x 5/24 = 0.12 years.

Sheep, Goats and Equine Animals

Sheep are kept outside all the year, except for approximately 1 month at lambing time (0.08 years). The same value is also used for goats.

Horses are stabled during 0.5 years, for the rest of the time they are kept outside on pastures.

C.6.2.2 Ratio of Nitrogen Excretion in Summer and Winter (Column E)

There is only a small difference between summer and winter diets. Therefore a ratio 1.1 is used.

C.6.3 EMISSION FACTORS

Irish agriculture is special as 93% of the area is grassland. In view of the climatic similarities with parts of the UK, UK emission factors are used with some exceptions.

C.6.3.1 Animal Houses in Winter and Summer (Column F and G)

Cattle

Cattle are housed in sheds with a concrete floors for 80% of the time. Dung and urine are scraped out daily or several times weekly into an outdoor containment facility. The rest of the cattle are housed in sheds with slatted floors. From Dutch experiments it is known that there is not much

Table C.11: Ireland 1990

	A	B	C	D	E	F	G	H	I
	Category		Calculation factors			Emission factors			
	Animals	Number of animals (x1000)	Inside winter (y)	Inside summer (y)	N excretion ratio summer/ winter	Animal houses winter (kg N/ hd/d)	Animal houses summer (kg N/ hd/d)	Grazing, N loss/N excreted	Spreading N loss/N applied
11	Total cattle	6,029							
12	> 2 y	3,069	0.37	0.12	1.10	0.04225	0.06413	0.080	0.285
13	1y< <2 y	1,538	0.37	0.00	1.10	0.03310	0.05025	0.080	0.285
14	< 1 y	1,422	0.75	0.00	1.10	0.01469	0.02216	0.080	0.285
16	Total pigs	1,069							
17	Pigs for slaugther	688	1.00			0.00907	0.00907		0.054
18	Boars and sows	129	1.00			0.02338	0.02338		0.054
20	Total sheep	6,001	0.08	0.00	1.00	0.00395	0.00839	0.046	0.285
22	Total goats	10	0.08	0.00	1.10	0.00395	0.00839	0.046	0.285
24	Equine & others	63	0.50	0.00	1.10	0.00988	0.02098	0.080	0.285
26	Total poultry	7,844							
27	Laying hens	4,241	1.00			0.00019	0.00019		0.376
28	Table fowl	3,603	1.00			0.00015	0.00015		0.072
30									
34	**Fertilisers**								Emission factor
36	Urea								0.150
37	Ammonium nitrate								0.010
38	Ammonium phosphate								0.050
39	Ammonium sulphate								0.050
40	Other								0.050
42									
45	**Industry**								
46	**Crops**								
47	**Miscellaneous**								
49									

Table C.11: Ireland 1990 (cont.)

J	K	L	M	N	O	P	Q	R	S	T
N Excretion					NH_3-N emissions					
Total (kg N/ hd/y)	Within animal house (kg N/ hd/y)	Outside animal house (kg N/ hd/y)	Total (kt N)	Total in slurry (kt N)	Animal houses (kt N)	Surface spreading (kt N)	Grazing (kt N)	Total (kt N)	% of N excreted	% per category
										68.9
97	45.81	51.19	298	114	26.1	32.6	12.6	71.3	24.0	
76	26.45	49.55	117	34	6.9	9.6	6.1	22.6	19.3	
33	24.15	8.85	47	29	5.7	8.2	1.0	14.9	31.7	
										2.5
12.8	12.80	0.00	9	7	2.3	0.4		2.6	29.9	
33	33.00	0.00	4	3	1.2	0.2		1.3	29.9	
20	1.60	18.40	120	9	1.0	2.5	5.1	8.5	7.1	5.4
20	1.47	18.53	0	0	0.0	0.0	0.0	0.0	6.9	0.0
50	23.81	26.19	3	1	0.1	0.4	0.1	0.6	20.5	0.4
										1.1
0.766	0.766	0.00	3	3	0.3	1.1		1.4	43.2	
0.348	0.348	0.00	1	1	0.2	0.1		0.3	21.8	
			602	**201**	**44**	**55**	**25**	**124**	**21**	**78.2**
			Fertiliser use (kt N)					NH_3-N losses (kt N)		
				60.6				9.1		
				311.7				3.1		
				0.0				0.0		
				2.1				0.1		
				4.1				0.2		
								12.5	**3.3**	**7.9**
								0.8		0.5
								8.5		5.4
								12.6		8.0
								158.0		**100.0**

difference in NH_3 emission in animal houses with concrete floors and slatted floors (Section C.3.2.1, Monteny, 1991). As a best estimate of storage losses, we use 10% of the N excretion (Monteny, 1991). Therefore the standard procedure including storage losses is used to calculate animal house emission factors (Section C.4.3.1, Germany).

Pigs

Generally manure or slurry is stored outside the animal house. As for the UK storage losses of 10% are added (Section C.4.3.1, Germany).

Sheep, Goats and Equine Animals

The same procedure as for Germany was used to calculate the animal house emission factors (Section C.4.3.3).

C.6.3.2 Spreading (Column I)

The Dutch emission factors are used (Section C.3.2.2), except for pigs where UK emission factors are used (Section C.5.3.2).

C.7 BELGIUM AND LUXEMBOURG (Table C.12)

C.7.1 CALCULATION FACTORS (Column C, D and E)

The Dutch calculation factors are used (Section C.3.1).

C.7.2 EMISSION FACTORS

C.7.2.1 Animal Houses in Winter and Summer (Column F and G)

Cattle

Dutch factors are used, corrected for differences in N excretion.

Pigs

For pigs UK emission factors (less storage losses) are used: Pigs for slaughter 0.00618; boars and saws 0.01593.

C.7.2.2 Spreading (Column I)

Cattle

Dutch data are used.

Pigs

Van den Abbeel *et al* (1989) measured gaseous N losses from surface applied pig slurry, using a wind tunnel method. The average dry matter content was 7.9%. Total N content of the slurry was 7.8 kg N/t. 60% of the total N was present as NH-N. NH_3-N emissions ranged from 18 to 33% of the total N applied, with an average of 24% (n=4). In another experiment up to 40% of the NH_4^+-N (corresponding to 28% of total N) volatilised (Vlassak *et al* 1991) at an application rate of 50 t/ha. These values are in the range of the Dutch values, but are higher than those of West Germany and the UK. Because of the similarity in results Dutch emission factors are used in Column I.

Table C.12: Belgium/Luxembourg 1990

	A	B	C	D	E	F	G	H	I
	Category		Calculation factors			Emission factors			
	Animals	Number of animals (x1000)	Inside winter (y)	Inside summer (y)	N excretion ratio summer/ winter	Animal houses winter (kg N/ hd/d)	Animal houses summer (kg N/ hd/d)	Grazing, N loss/ N excreted	Spreading N loss/N applied
11	Total cattle	3,361							
12	> 2 y	1,676	0.50	0.20	1.25	0.01936	0.04112	0.080	0.285
13	1-2 y	727	0.50	0.00	1.25	0.01501	0.03189	0.080	0.285
14	< 1 y	958	0.75	0.00	1.25	0.00652	0.01385	0.080	0.285
16	Total pigs	6,495							
17	Pigs for slaugther	4,148	1.00			0.00618	0.00618		0.285
18	Boars and sows	663	1.00			0.01593	0.01593		0.285
20	Total sheep	143	0.20	0.00	1.25	0.00395	0.00839	0.046	0.285
22	Total goats	9	0.20	0.00	1.25	0.00237	0.00503	0.08	0.285
24	Equine	21	0.50	0.00	1.25	0.00988	0.02098	0.080	0.285
26	Total poultry	23,343							
27	Laying hens	10,944	1.00			0.00019	0.00019		0.376
28	Table fowl	12,399	1.00			0.00015	0.00015		0.072
30									
34	**Fertilisers**								Emission factor
36	Urea								0.150
37	Ammonium nitrate								0.020
38	Ammonium phosphate								0.050
39	Ammonium sulphate								0.100
40	Other								0.000
42									
45	**Industry**								
46	**Crops**								
47	**Miscellaneous**								
49									

Table C.12: Belgium/Luxembourg 1990 (cont.)

J	K	L	M	N	O	P	Q	R	S	T
N Excretion					NH_3-N emissions					
Total (kg N/ hd/y)	Within animal house (kg N/ hd/y)	Outside animal house (kg N/ hd/y)	Total (kt N)	Total in slurry (kt N)	Animal houses (kt N)	Surface spreading (kt N)	Grazing (kt N)	Total (kt N)	% of N excreted	% per category
										54.3
98	65.33	32.67	164	99	11.0	28.1	4.4	43.4	26.4	
76	33.78	42.22	55	23	2.0	6.4	2.5	10.9	19.7	
33	23.29	9.71	32	21	1.7	5.9	0.7	8.3	26.3	
										26.7
12.8	12.80	0.00	53	44	9.4	12.5		21.8	41.1	
33	33.00	0.00	22	18	3.9	5.1		9.0	41.1	
20	3.33	16.67	3	0	0.0	0.1	0.1	0.3	9.8	0.2
20	3.33	16.67	0	0	0.0	0.0	0.0	0.0	9.8	0.0
50	22.22	27.78	1	0	0.0	0.1	0.0	0.2	19.8	0.2
										4.0
0.766	0.766	0.00	8	8	0.8	2.9		3.6	43.2	
0.348	0.348	0.00	4	4	0.7	0.3		0.9	21.8	
		Subtotal	**343**	**216**	**29**	**61**	**8**	**99**	**29**	**85.4**
			Fertiliser use (kt N)					NH_3-N losses (kt N)		
				2.0				0.3		
				180.0				3.6		
				1.0				0.1		
				2.3				0.2		
				5.0				0.0		
			Subtotal	**190.3**				**4.2**	**2.2**	**3.6**
								1.1		1.0
								2.3		2.0
								9.2		8.0
							Total	**115.4**		**100.0**

C.8 ITALY (Table C.13)

C.8.1 CALCULATION FACTORS

C.8.1.1 Inside Winter and Summer (Column C and D)

Cattle

A large majority of cattle are kept indoors during the whole year (Manstretta, 1991). Factors for indoors on winter diet and indoors on summer diet are thus 1 and 0 years, respectively.

Sheep, Goats and Equine Animals

Sheep are mostly outside during the whole year, except at lambing time, when they are stabled for approximately 1 month (0.08 years). The same is probably the case for goats. Horses and donkeys are kept indoors for 0.5 years.

C.8.1.2 Nitrogen Excretion in Summer and Winter (Column E)

There is no remarkable difference in N content between summer and winter diets of cattle, sheep, goats and horses (ratio 1).

C.8.2 EMISSION FACTORS

C.8.2.1 Animal Houses in Winter and Summer (Column F and G)

Cattle

Dairy cows are kept in houses on straw-covered floors whilst beef cattle are kept in sheds without litter (slurry production) (Manstretta, 1991). The overall NH_3 emissions are approximately the same for both systems previously discussed.

For Italy the standard procedure for calculating the emission factors should be supplemented with corrections for temperature differences and differences in storage losses. The average year temperature for the Netherlands is 9°C and for Italy 15°C. The ratio of NH_3 emissions from cattle houses in the Netherlands and in Italy is then: 1: 1.19 using the regression equation of Oldenburg (1989) (Equation C.17, Section C.4.3.1). This means an average emission in winter and summer, based on the equations presented for the Netherlands (C.14 and C.17):

$$F12 = 1.19 \times 0.02825 \times N_{excretion} / 143 \quad \text{(Eq. C.29)}$$

$$G12 = 1.19 \times 0.06 \times N_{excretion} / 143 \quad \text{(Eq. C.30)}$$

In Italy storage capacity for all types of slurry and manure is 120 to 180 days. Estimated emissions during storage are approximately 20% for an average storage time of 150 days.

Corrections for storage losses were done as described for Germany, Section 4.3.1.

Pigs

In Italy there are only 1.85 cycles of pigs for slaughter/y, because they are fattened till they reached a weight of 130 to 150 kg/pig. The N excretion of a pig from 25 kg up to 140 kg is approximately 10 kg N or approximately 18.5 kg N/pig place. Otherwise standard values are used.

Pigs are kept on slatted floors. 60% of the slurry has an average dry matter content of 4-5%. The remaining 40% has a dry-matter content of less than 1% due to dilution by washing-down water (Manstretta, 1991). So average dry-matter content is approximately 2% which is the same as in West Germany. Hence the West German emission factor for slatted floors is used (0.00564 kg N/hd/day), corrected for temperature and N excretion. The average year temperature is 7.9°C for West Germany and 15.0°C for Italy. This gives an emission ratio of: 1:1.26. The daily emission rate is now calculated as $1.26 \times (0.00564 \times N_{excretion}/12.8) = 0.01027$.

Following storage-loss-corrections the factors F17 + G17 become 0.01835 and F18 + G18 become 0.03274 kg N/hd/day for pigs for slaughter, and boars and sows respectively.

Sheep, Goats and Equine Animals

The same factors as for the Netherlands are used, corrected for N excretion and temperature (ratio 1.19).

Poultry

In Italy laying hens are mostly kept in batteries, whilst broilers are kept on floors covered by wood chips (Manstretta, 1991). Dutch factors, corrected for temperature, are used for estimating emissions. Oldenburg (1989) derived a regression equation between the temperature of air

Table C.13: Italy 1990

	A	B	C	D	E	F	G	H	I
	Category		Calculation factors			Emission factors			
	Animals	Number of animals (x1000)	Inside winter (y)	Inside summer (y)	N excretion ratio summer/ winter	Animal houses winter (kg N/ hd/d)	Animal houses summer (kg N/ hd/d)	Grazing, N loss/N excreted	Spreading N loss/N applied
11	Total cattle	8,235							
12	> 2 y	3,989	0.50	0.50	1.00	0.07139	0.09190	0.080	0.220
13	1-2 y	1,701	0.50	0.50	1.00	0.05594	0.07200	0.080	0.220
14	< 1 y	2,545	0.50	0.50	1.00	0.02429	0.03126	0.080	0.220
16	Total pigs	8,837							
17	Pigs for slaugther	6,549	1.00			0.01835	0.01835		0.140
18	Boars and sows	723	1.00			0.03274	0.03274		0.140
20	Total sheep	8,134	0.08	0.00	1.00	0.00470	0.00999	0.046	0.220
22	Total goats	1,298	0.08	0.00	1.00	0.00470	0.00999	0.046	0.220
24	Equine	350	0.50	0.00	1.00	0.01175	0.02497	0.080	0.220
266	Total poultry	149,347							
27	Laying hens	79,189	1.00			0.00024	0.00024		0.376
28	Table fowl	70,158	1.00			0.00018	0.00018		0.072
30									
34	**Fertilisers**								Emission factor
36	Urea								0.150
37	Ammonium nitrate								0.020
38	Ammonium phosphate								0.050
39	Ammonium sulphate								0.100
40	Other								0.000
42									
45	**Industry**								
46	**Crops**								
47	**Miscellaneous**								
49									

Table C.13: Italy 1990 (cont.)

J	K	L	M	N	O	P	Q	R	S	T
N Excretion					NH_3-N emissions					
Total (kg N/ hd/y)	Within animal house (kg N/ hd/y)	Outside animal house (kg N/ hd/y)	Total (kt N)	Total in slurry (kt N)	Animal houses (kt N)	Surface spreading (kt N)	Grazing (kt N)	Total (kt N)	% of N excreted	% per category
										53.0
97	97.00	0.00	387	268	118.9	59.0	0.0	177.8	46.0	
76	76.00	0.00	129	90	39.7	19.7	0.0	59.4	46.0	
33	33.00	0.00	84	58	25.8	12.8	0.0	38.6	46.0	
										12.6
18.5	18.50	0.00	121	77	43.9	10.8		54.7	45.1	
33	33.00	0.00	24	15	8.6	2.1		10.8	45.1	
20	1.60	18.40	163	12	1.5	2.5	6.9	10.9	6.7	2.1
20	1.60	18.40	26	2	0.2	0.4	1.1	1.7	6.7	0.3
50	25.00	25.00	18	8	0.8	1.8	0.7	3.2	18.5	0.6
										6.4
0.766	0.766	0.00	61	54	6.8	20.2		27.1	44.6	
0.348	0.348	0.00	24	20	4.6	1.4		6.0	24.7	
		Subtotal	**1,036**	**603**	**251**	**131**	**9**	**390**	**38**	**75.0**
			Fertiliser use (kt N)					NH_3-N losses (kt N)		
			320.0					48.0		
			380.0					7.6		
			51.0					2.6		
			58.0					5.8		
			18.0					0.0		
		Subtotal	**827.0**					64.0	7.7	12.3
								3.3		0.6
								21.0		4.0
								41.6		8.0
							Total	**520.2**		**100.0**

entering a laying hen house (Equation C.28). The average year temperature is 9°C for the Netherlands and 15.0°C for Italy. This gives an emission ratio of approximately 1:1.24. The daily emission rate is now calculated as 1.24x0.00019 = 0.000236 kg N/a/day for laying hen houses and 1.24x0.000145=0.00018 kg N/a/day for broiler houses.

The estimate is supported by the results of Valli *et al* (1991): 0.00017 kg NH_3-N/hen/day was lost from a ventilated deep pit poultry (laying hen) house. They measured up to 0.594 kg NH_3-N/hen/y emission during composting of manure from animal houses where the manure was removed daily. These emissions are even higher than those for the Netherlands.

C.8.2.2 **Grazing** (Column H)

The proportion of the excreted N that volatilises may be higher than in the UK and the Netherlands due to the warm weather conditions (Vallis *et al*, 1982). However, it is not necessary to change the emission factor for grazing for Italy, because almost all cattle remain indoors.

C.8.2.3 **Spreading** (Column I)

Cattle

Approximately 2/3 of the cattle manure is farmyard manure. The rest is slurry. Approximately 20% of the N in farmyard manure and 59% of that in slurry is NH_4^+-N. If it is assumed that, as in the Netherlands, 57% of the NH_4^+-N volatilises, then the average emission factor in Italy is (0.33x0.2+0.66x0.5)x0.57= 0.225. This is almost identical to the German value of 0.22 (Section C.4.3.1). Therefore 0.22 is used for Italy.

Pigs

The German emission factor for spreading is used for Italy, because of the similar low dry matter content of the pig slurries in both countries. In addition, slurries are applied in both countries at the end of the winter or in early spring, periods in which the weather conditions of both countries are comparable.

Sheep, Goats, Equine Animals and Poultry

Spreading factors used for Germany are used (Section C.4.5.3).

As discussed previously, grazing emission factors are 0.046 for sheep and goats and 0.08 for cattle and equine.

C.9 FRANCE (Table C.14)

C.9.1 CALCULATION FACTORS

C.9.1.1 Inside Winter and Summer (Column C and D)

Cattle

Cattle are on average stabled for 6-7 month (0.55 years). During summer (165 days) the cows are only in the shed during milking time (5 hours/day). This corresponds to a period of 0.09 years.

Sheep, Goats and Equine Animals

On average, sheep are stabled for 4-6 months (0.42 years) and goats for 8 months (0.67 years). Equine animals are stabled for 3 months (0.25 years). During the rest of the year sheep, goats and equine animals are grazing on pastures.

C.9.1.2 Nitrogen Excretion in Summer and Winter (Column E)

There is only a small difference between summer and winter diets. Therefore a ratio 1.1 is used.

C.9.2 EMISSION FACTORS

C.9.2.1 Animal Houses in Winter and Summer (Column F and G)

Cattle

Approximately 80% of the cattle are housed in sheds on straw, but as previously discussed the overall NH_3 emissions are approximately the same for a slurry and farmyard manure system. Generally, slurry is stored outside the house. It is assumed that the emissions from storage are the average of German and Italian values i.e. 15%. Thus standard procedure (Section 4.3.1, Germany) is used to calculate animal house emission including storage losses.

Pigs

The UK emission factors are used for animal house emissions (Section C.5.3.1). Generally slurry or manure is stored outside the house. Therefore storage losses of 15% are included (see procedure Germany, Section C.4.3.1).

C.9.2.2 **Spreading** (Column I)

Ferenzi and Taureau (1992) have published N efficiency coefficients for manures. These vary from 0.15 to 0.8, depending on crop manure type and season for its application. They reflect N losses both from leaching and NH_3 volatilisation, and also that part of the N in manure is not available to crops in the growing season following application.

There are no emission factors relating to NH_3 emissions alone. Hence Allemand (1992) used the old factors of Buijsman *et al* (1992) for their estimate of NH_3 emissions in France. However, 20% seems an appropriate emission factor from the sparse material available. This may give an underestimate of emissions following spreading of pig slurry and overestimate emission from farmyard manures rich in straw, but there is no material on which estimate can be made. Hence a factor 0.2 is used for all animal categories except for poultry where the Dutch emission factors are used, because the N content in poultry manure is much higher than from cattle.

Table C.14 France 1990

	A	B	C	D	E	F	G	H	I
	Category		Calculation factors			Emission factors			
	Animals	Number of animals (x1000)	Inside winter (y)	Inside summer (y)	N excretion ratio summer/ winter	Animal houses winter (kg N/ hd/d)	Animal houses summer (kg N/ hd/d)	Grazing, N loss/N excreted	Spreading N loss/N applied
11	Total cattle	21,446							
12	> 2 y	11,627	0.55	0.09	1.10	0.05724	0.08050	0.080	0.200
13	1-2 y	4,110	0.55	0.00	1.10	0.04265	0.05998	0.080	0.200
14	< 1 y	5,709	0.55	0.00	1.10	0.01852	0.02604	0.080	0.200
16	Total pigs	12,013							
17	Pigs for slaugther	8,138	1.00			0.01051	0.01051		0.200
18	Boars and sows	1105	1.00			0.02710	0.02710		0.200
20	Total sheep	11,071	0.42	0.00	1.10	0.00395	0.00839	0.046	0.200
22	Total goats	1,162	0.67	0.00	1.10	0.00395	0.00839	0.046	0.200
24	Equine	344	0.25	0.00	1.10	0.00988	0.02098	0.080	0.200
26	Total poultry	224,908							
27	Laying hens	67,390	1.00			0.00019	0.00019		0.376
28	Table fowl	157,518	1.00			0.00015	0.00015		0.072
30									
34	**Fertilisers**								Emission factor
36	Urea								0.150
37	Ammonium nitrate								0.020
38	Ammonium phosphate								0.050
39	Ammonium sulphate								0.100
40	Other								0.080
42									
45	**Industry**								
46	**Crops**								
47	**Miscellaneous**								
49									

Table C.14 France 1990 (cont.)

J	K	L	M	N	O	P	Q	R	S	T
N Excretion					NH_3-N emissions					
Total (kg N/ hd/y)	Within animal house (kg N/ hd/y)	Outside animal house (kg N/ hd/y)	Total (kt N)	Total in slurry (kt N)	Animal houses (kt N)	Surface spreading (kt N)	Grazing (kt N)	Total (kt N)	% of N excreted	% per category
										53.7
102	63.35	38.65	1,186	572	164.4	114.4	36.0	314.7	26.5	
76	40.00	36.00	312	129	35.2	25.8	11.8	72.9	23.3	
33	17.37	15.63	188	78	21.2	15.6	7.1	43.9	23.3	
										7.7
12.8	12.80	0.00	104	73	31.2	14.6		45.8	44.0	
33	33.00	0.00	36	26	10.9	5.1		16.0	44.0	
20	7.94	12.06	221	81	7.2	16.1	6.1	29.5	13.3	3.7
20	12.97	7.03	23	14	1.2	2.8	0.4	4.3	18.6	0.5
50	11.63	38.37	17	4	0.3	0.7	1.1	2.1	12.4	0.3
										4.3
0.766	0.766	0.00	52	47	4.7	17.7		22.3	43.2	
0.348	0.348	0.00	55	46	8.6	3.3		11.9	21.8	
		Subtotal	**2,196**	**1,069**	**285**	**216**	**63**	**564**	**26**	**70.1**
			Fertiliser use (kt N)					NH_3-N losses (kt N)		
			266.5					40.0		
			1,743.7					34.9		
			0.0					0.0		
			37.8					3.8		
			612.0					49.0		
		Subtotal	**2,660.0**					127.6	4.8	15.9
								2.0		0.2
								46.1		5.7
								64.3		8.0
							Total	**803.6**		**100.0**

C.10 GREECE (Table C.15)

C.10.1 CALCULATION FACTORS

C.10.1.1 Inside Winter and Summer (Column C and D)

Cattle

Cattle are kept mostly inside all the year, as in Italy.

Sheep, Goats and Equine Animals

Sheep and goats are kept at rough grazing most of the year, as in Italy.

C.10.1.2 Nitrogen Excretion in Summer and Winter (Column E)

There is little difference between summer and winter ration (ratio 1.0)

C.10.2 EMISSION FACTOR

C.10.2.1 Animal Houses in Winter and Summer (Column F and G)

Cattle, sheep, equine and poultry

Emission factors and emission calculation procedures used for Italy are also used for Greece, as it is assumed that conditions in Greek agriculture are more comparable with those in Italy than with those in the Netherlands, West Germany or the UK.

Pigs

For pigs for slaughter the Italian value is corrected for N excretion, where the standard value (12.8) is used for Greece. This gives a factor 12.8/18.5 x 0.01035 = 0.01270 kg N/hd/day.

C.10.2.2 Spreading (Column I)

German factors are used as for Italy.

Table C.15: Greece 1990

	A	B	C	D	E	F	G	H	I
	Category		Calculation factors			Emission factors			
	Animals	Number of animals (x1000)	Inside winter (y)	Inside summer (y)	N excretion ratio summer/ winter	Animal houses winter (kg N/ hd/d)	Animal houses summer (kg N/ hd/d)	Grazing, N loss/N excreted	Spreading N loss/N applied
11	Total cattle	687							
12	> 2 y	369	0.50	0.50	1.00	0.06330	0.08148	0.080	0.220
13	1-2 y	102	0.50	0.50	1.00	0.05594	0.07200	0.080	0.220
14	< 1 y	216	0.50	0.50	1.00	0.02429	0.03126	0.080	0.220
16	Total pigs	1,143							
17	Pigs for slaugther	633	1.00			0.01270	0.01270		0.140
18	Boars and sows	160	1.00			0.03274	0.03274		0.140
20	Total sheep	10,150	0.08	0.00	1.00	0.00470	0.00999	0.046	0.220
22	Total goats	5,918	0.08	0.00	1.00	0.00470	0.00999	0.046	0.220
24	Equine	190	0.50	0.00	1.00	0.01175	0.02497	0.080	0.220
26	Total poultry	29,752							
27	Laying hens	15,207	1.00			0.00024	0.00024		0.376
28	Table fowl	14,545	1.00			0.00018	0.00018		0.072
30									
34	**Fertilisers**								Emission factor
36	Urea								0.200
37	Ammonium nitrate								0.030
38	Ammonium phosphate								0.050
39	Ammonium sulphate								0.150
40	Other								0.000
42									
45	**Industry**								
46	**Crops**								
47	**Miscellaneous**								
49									

Table C.15: Greece 1990 (cont.)

J	K	L	M	N	O	P	Q	R	S	T
N Excretion					NH_3-N emissions					
Total (kg N/ hd/y)	Within animal house (kg N/ hd/y)	Outside animal house (kg N/ hd/y)	Total (kt N)	Total in slurry (kt N)	Animal houses (kt N)	Surface spreading (kt N)	Grazing (kt N)	Total (kt N)	% of N excreted	% per category
										21.9
86	86.00	0.00	32	22	9.7	4.8	0.0	14.6	46.0	
76	76.00	0.00	8	5	2.4	1.2	0.0	3.6	46.0	
33	33.00	0.00	7	5	2.2	1.1	0.0	3.3	46.0	
										6.2
12.8	12.80	0.00	8	5	2.9	0.7		3.7	45.1	
33	33.00	0.00	5	3	1.9	0.5		2.4	45.1	
20	1.60	18.40	203	14	1.9	3.2	8.6	13.6	6.7	13.9
20	1.60	18.40	118	8	1.1	1.8	5.0	7.9	6.7	8.1
50	25.00	25.00	10	4	0.4	1.0	0.4	1.8	18.5	1.8
										6.6
0.766	0.766	0.00	12	10	1.3	3.9		5.2	44.6	
0.348	0.348	0.00	5	4	1.0	0.3		1.3	24.7	
		Subtotal	**408**	**82**	**25**	**18**	**14**	**57**	**14**	**58.4**
			Fertiliser use (kt N)				NH_3-N losses (kt N)			
				9.1				1.8		
				354.0				10.6		
				0.0				0.0		
				41.1				6.2		
				0.0				0.0		
			Subtotal	**404.2**				18.6	4.6	19.0
								0.5		0.5
								13.8		14.1
								7.8		8.0
							Total	**98.0**		**100.0**

C.11 PORTUGAL (Table C.16)

C.11.1 CALCULATION FACTORS

C.11.1.1 Inside Winter and Summer (Column C and D)

Cattle

Dairy production in Portugal is located mainly in the north-west. Management in this region is intensive with the animals stabled all year. This represents 1/3 of the number of the cattle. The remaining 2/3 of the number of cattle are rough grazed for meat production. Thus the overall period of winter ration is 0.7 years, of which 0.5 years in winter and 0.2 years in summer. Hence the factors 0.5 and 0.2 are used in Columns C and D.

Sheep, Goats and Equine Animals

The Italian calculation factors are used.

C.11.1.2 Nitrogen Excretion in Summer and Winter (Column E)

The ratio between N in summer and winter diets is assumed to be 1.15.

C.11.2 EMISSION FACTORS

C.11.2.1 Animal Houses in Winter and Summer (Column F and G)

Cattle

Emission factors and emission calculation procedures used for Italy are also used for Portugal, as it is assumed that conditions in Portuguese agriculture are more comparable with those in Italy than with those in the Netherlands, West Germany or the UK.

Pigs

The factors used for Italy are also used for Portugal, but corrected for $N_{excretion}$ in the case of pigs for slaughter, as described for Greece.

C.11.2.2 **Spreading** (Column I)

German factors are used like also done in Italy, except for cattle where the Italian value is used (Section C.8.2.3).

Table C.16: Portugal 1990

	A	B	C	D	E	F	G	H	I
	Category		Calculation factors			Emission factors			
	Animals	Number of animals (x1000)	Inside winter (y)	Inside summer (y)	N excretion ratio summer/ winter	Animal houses winter (kg N/ hd/d)	Animal houses summer (kg N/ hd/d)	Grazing, N loss/N excreted	Spreading N loss/N applied
11	Total cattle	1,340							
12	> 2 y	693	0.50	0.20	1.15	0.06629	0.09363	0.080	0.220
13	1-2 y	242	0.50	0.20	1.15	0.05303	0.07491	0.080	0.220
14	< 1 y	405	0.50	0.20	1.15	0.02303	0.03253	0.080	0.220
16	Total pigs	2,664							
17	Pigs for slaugther	1,553	1.00			0.01270	0.01270		0.140
18	Boars and sows	345	1.00			0.03274	0.03274		0.140
20	Total sheep	3,360	0.08	0.00	1.15	0.00470	0.00999	0.046	0.220
22	Total goats	857	0.08	0.00	1.15	0.00470	0.00999	0.046	0.220
24	Equine	191	0.50	0.00	1.15	0.01175	0.02497	0.080	0.220
26	Total poultry	31,499							
27	Laying hens	8,996	1.00			0.00024	0.00024		0.376
28	Table fowl	22,503	1.00			0.00018	0.00018		0.072
30									
34	**Fertilisers**								Emission factor
36	Urea								0.150
37	Ammonium nitrate								0.020
38	Ammonium phosphate								0.050
39	Ammonium sulphate								0.100
40	Other								0.000
42									
45	**Industry**								
46	**Crops**								
47	**Miscellaneous**								
49									

Table C.16: Portugal 1990 (cont.)

J	K	L	M	N	O	P	Q	R	S	T
N Excretion					NH_3-N emissions					
Total (kg N/ hd/y)	Within animal house (kg N/ hd/y)	Outside animal house (kg N/ hd/y)	Total (kt N)	Total in slurry (kt N)	Animal houses (kt N)	Surface spreading (kt N)	Grazing (kt N)	Total (kt N)	% of N excreted	% per category
										41.4
95	64.51	30.49	66	32	13.1	6.9	1.7	21.8	33.1	
76	51.61	24.39	18	9	3.7	1.9	0.5	6.1	33.1	
33	22.41	10.59	13	6	2.7	1.4	0.3	4.4	33.1	
										18.1
12.8	12.80	0.00	20	13	7.2	1.8		9.0	45.1	
33	33.00	0.00	11	7	4.1	1.0		5.1	45.1	
20	1.41	18.59	67	4	0.6	0.9	2.9	4.4	6.5	5.6
20	1.41	18.59	17	1	0.2	0.2	0.7	1.1	6.5	1.4
50	23.26	26.74	10	4	0.4	0.9	0.4	1.7	18.0	2.2
										6.4
0.766	0.766	0.00	7	6	0.8	2.3		3.1	44.6	
0.348	0.348	0.00	8	6	1.5	0.5		1.9	24.7	
		Subtotal	**237**	**88**	**34**	**18**	**7**	**59**	**25**	**75.2**
			Fertiliser use (kt N)				NH_3-N losses (kt N)			
				17.0				2.6		
				110.5				2.2		
				1.7				0.1		
				13.4				1.3		
				2.8				0.0		
			Subtotal	**145.4**				6.2	4.3	7.9
								0.1		0.2
								6.8		8.7
								6.2		8.0
							Total	**78.0**		**100.0**

C.12 SPAIN (Table C.17)

Agricultural conditions are very different in northern - North-West Spain from that in the rest of the country. Northern Spain has predominantly acidic soils, and substantial rain ensures lush pastures in the grazing season (March-September). Approximately 80% of the dairy production is in this region. The rest of Spain has predominantly alkaline calcareous soils, and a rather dry climate.

C.12.1 CALCULATION FACTORS

C.12.1.1 Inside Winter and Summer (Column C and D)

The same factors as for Italy are used.

Cattle

Approximately 40% of the cattle are stabled all year. The rest are grazing approximately 6 months, with a ratio of 1.25 between summer and winter rations. Thus on average cattle are stabled 0.7 earsy; 0.5 years in winter and 0.2 years in summer.

Sheep, Goats and Equine Animals

Italian calculation factors are used.

C.12.1.2 Nitrogen Excretion in Summer and Winter

For stabled cattle (40%), there are no notable differences between summer and winter rations. For grazing animals, the ratio is 1.25. This gives a combined ratio 1.15.

C.12.2 EMISSION FACTORS

C.12.2.1 Animal Houses in Winter and Summer (Column F and G)

Cattle

Emission factors and emission calculation procedures used for Italy are also used for Spain, as it is assumed that conditions in Spanish agriculture are more comparable with those in Italy than with those in the Netherlands, West Germany or the UK.

Pigs

It is assumed that pigs are stabled all year, though the tradition of letting pigs feed on acorns may be reviving to some extent.

C.12.2.2 Spreading

German factors are used as for Italy.

Table C.17: Spain 1990

	A	B	C	D	E	F	G	H	I
	Category		Calculation factors			Emission factors			
	Animals	Number of animals (x1000)	Inside winter (y)	Inside summer (y)	N excretion ratio summer/ winter	Animal houses winter (kg N/ hd/d)	Animal houses summer (kg N/ hd/d)	Grazing, N loss/N excreted	Spreading N loss/N applied
11	Total cattle	5,001							
12	> 2 y	2,926	0.50	0.20	1.15	0.06559	0.09265	0.080	0.220
13	1-2 y	583	0.50	0.20	1.15	0.05303	0.07491	0.080	0.220
14	< 1 y	1,492	0.50	0.20	1.15	0.02303	0.03253	0.080	0.220
16	Total pigs	15,949							
17	Pigs for slaugther	10,162	1.00			0.01270	0.01270		0.140
18	Boars and sows	1,819	1.00			0.03274	0.03274		0.140
20	Total sheep	24,022	0.08	0.00	1.15	0.00470	0.00999	0.046	0.220
22	Total goats	5,014	0.08	0.00	1.15	0.00470	0.00999	0.046	0.220
24	Equine	406	0.08	0.00	1.15	0.01175	0.02497	0.080	0.220
26	Total poultry	125,338							
27	Laying hens	43,967	1.00			0.00024	0.00024		0.376
28	Table fowl	81,371	1.00			0.00018	0.00018		0.072
30									
34	**Fertilisers**								Emission factor
36	Urea								0.200
37	Ammonium nitrate								0.030
38	Ammonium phosphate								0.050
39	Ammonium sulphate								0.150
40	Other								0.080
42									
45	**Industry**								
46	**Crops**								
47	**Miscellaneous**								
49									

Table C.17: Spain 1990 (cont.)

J	K	L	M	N	O	P	Q	R	S	T
N Excretion					NH_3-N emissions					
Total (kg N/ hd/y)	Within animal house (kg N/ hd/y)	Outside animal house (kg N/ hd/y)	Total (kt N)	Total in slurry (kt N)	Animal houses (kt N)	Surface spreading (kt N)	Grazing (kt N)	Total (kt N)	% of N excreted	% per category
										27.1
94	63.83	30.17	275	132	54.8	29.0	7.1	90.9	33.1	
76	51.61	24.39	44	21	8.8	4.7	1.1	14.6	33.1	
33	22.41	10.59	49	24	9.8	5.2	1.3	16.3	33.1	
										19.1
12.8	12.80	0.00	130	83	47.1	11.6		58.7	45.1	
33	33.00	0.00	60	38	21.7	5.4		27.1	45.1	
20	1.41	18.59	480	29	4.4	6.5	20.5	31.4	6.5	7.0
20	1.41	18.59	100	6	0.9	1.3	4.3	6.6	6.5	1.5
50	3.51	46.49	20	1	0.2	0.3	1.5	2.0	9.6	0.4
										4.9
0.766	0.766	0.00	34	30	3.8	11.2		15.0	44.6	
0.348	0.348	0.00	28	23	5.3	1.7		7.0	24.7	
		Subtotal	**1,222**	**388**	**157**	**77**	**36**	**270**	**22**	**60.0**
			Fertiliser use (kt N)				NH_3-N losses (kt N)			
				283.4				56.7		
				624.7				18.7		
				50.8				2.5		
				94.0				14.1		
				49.9				4.0		
		Subtotal		**1,102.8**				96.1	8.7	21.4
								1.8		0.4
								45.8		10.2
								35.9		8.0
							Total	**449.2**		**100.0**

C.13 DENMARK (Table C.18)

C.13.1 CATEGORY AND NUMBER OF ANIMALS (Column A and B)

Horses in riding and trotting centers are not listed in the Eurostat statistics, nor are private riding horses. Current total horse population is approximately 80,000, estimated by breeders.

C.13.2 CALCULATION FACTORS

C.13.2.1 Inside Winter and Summer (Column C and D)

Cattle

In Denmark 70% of the cattle are grazed for 5 months/year. Consequently, 0.65 year is used as the period for indoors on winter diet and 0.1 as the period for indoors on summer diet. For calves the Dutch factor 0.75 years is used.

Sheep, Goats and Equine Animals

Sheep are grazing 4 months/year. We assume that the same is true for goats and horses. This corresponds with a period 0.35 years in Cell C and a factor 0.1 years in Cell D.

C.13.2.2 Nitrogen Excretion in Summer and Winter (Column E)

The Dutch ratio is used.

C.13.3 EMISSION FACTOR

C.13.3.1 Animal Houses in Winter and Summer (Column F and G)

Cattle

Emission factor corrected for N excretion for the Netherlands are also used for Denmark.

Pigs

As discussed in Section C.2.4.1 the annual $N_{excretion}$ per pig place was 12.8 kg N for pigs for slaughter and 38.9 kg N for sows.

We use the calculation procedure described for UK, taking the average of dutch and german emission factors for sheds (excluding storage losses), but adjusted using the Danish excretion data:

Pigs for slaughter: Cells F17-G17: $(0.00595 \times \frac{12.8}{12.8} + 0.0068 \times \frac{12.8}{13.6}) / 2 = 0.00618$ (Eq. C.31)

For boars and sows linear extrapolation as described in Section 4.3.1 is used:

Cells F18-G18: $0.00618 \times \frac{38.9}{12.8} = 0.01878$ (Eq. C.32)

C.13.3.2 Spreading (Column I)

Cattle

Christensen (1988), using a wind-tunnel system, measured NH_3 volatilisation from surface applied cattle manure under sustained drying conditions in autumn.

When slurry was applied at a rate of 30 m^3/ha, total N emissions expressed as a percentage of that applied were 57% for cattle (n=5) and 53% for pig slurry (n=3). These emissions do not seem to be representative, they are much higher than average NH_3 losses from surface applied cattle slurry in the Netherlands, Germany and the UK.

Sommer *et al* (1991) found by experiments with a wind tunnel system that surface applied cattle slurry lost between 20 and 50% of the nitrogen through NH_3 emission. Sommer suggests that a representative value for emissions in Denmark based on his experiments is around 30%. This is close to the value of 28.5% found in the Netherlands. The factor 0.285 as used for the Netherlands, Belgium, the UK and Ireland is therefore adopted for the Nordic countries.

Table C.18: Denmark 1990

	A	B	C	D	E	F	G	H	I
	Category		Calculation factors			Emission factors			
	Animals	Number of animals (x1000)	Inside winter (y)	Inside summer (y)	N excretion ratio summer/ winter	Animal houses winter (kg N/ hd/d)	Animal houses summer (kg N/ hd/d)	Grazing, N loss/N excreted	Spreading N loss/N applied
11	Total cattle	2,241							
12	> 2 y	970	0.65	0.10	1.25	0.02548	0.05413	0.080	0.285
13	1-2 y	425	0.65	0.00	1.25	0.01501	0.03189	0.080	0.285
14	< 1 y	846	0.75	0.00	1.25	0.00652	0.01385	0.080	0.285
16	Total pigs	9,282							
17	Pigs for slaugther	5,517	1.00 1.00			0.00618	0.00618		0.285
18	Boars and sows	933				0.01878	0.01878		0.285
20	Total sheep	111	0.65	0.00	1.25	0.00672	0.01427	0.046	0.285
22	Total goats	0	0.65	0.00	1.25	0.00672	0.01427	0.046	0.285
24	Equine	80	0.65	0.00	1.25	0.00988	0.02098	0.080	0.285
26	Total poultry	15,540							
27	Laying hens	5,938	1.00			0.00019	0.00019		0.376
28	Table fowl	9,602	1.00			0.00015	0.00015		0.072
30									
34	**Fertilisers**								Emission factor
36	Urea								0.150
37	Ammonium nitrate								0.010
38	Ammonium phosphate								0.050
39	Ammonium sulphate								0.050
40	Other								0.040
42									
45	**Industry**								
46	**Crops**								
47	**Miscellaneous**								
49									

Table C.18: Denmark 1990 (cont.)

J	K	L	M	N	O	P	Q	R	S	T
N Excretion					NH_3-N emissions					
Total (kg N/ hd/y)	Within animal house (kg N/ hd/y)	Outside animal house (kg N/ hd/y)	Total (kt N)	Total in slurry (kt N)	Animal houses (kt N)	Surface spreading (kt N)	Grazing (kt N)	Total (kt N)	% of N excreted	% per category
										41.1
129	91.93	37.07	125	81	7.8	23.2	2.9	33.9	27.1	
76	45.43	30.57	32	18	1.5	5.1	1.0	7.6	23.6	
33	23.29	9.71	28	18	1.5	5.2	0.7	7.4	26.3	
										37.0
12.8	12.80	0.00	71	58	12.4	16.6		29.0	41.1	
38.9	38.90	0.00	36	30	6.4	8.5		14.9	41.1	
34	20.32	13.68	4	2	0.2	0.6	0.1	0.8	22.3	0.7
34	20.32	13.68	0	0	0.0	0.0	0.0	0.0	0.0	0.0
50	29.89	20.11	4	2	0.2	0.6	0.1	0.9	23.7	0.8
										2.3
0.766	0.766	0.00	5	4	0.4	1.6		2.0	43.2	
0.348	0.348	0.00	3	3	0.5	0.2		0.7	21.8	
		Subtotal	**308**	**217**	**31**	**62**	**5**	**97**	**32**	**81.8**
			Fertiliser use (kt N)					NH_3-N losses (kt N)		
				9.2				1.4		
				318.7				3.2		
				2.9				0.1		
				0.6				0.0		
				69.0				2.8		
			Subtotal	**400.4**				**7.5**	**1.9**	**6.3**
								0.4		0.3
								4.2		3.5
								9.5		8.0
							Total	**118.9**		**100.0**

C.14 NORWAY (Table C.19)

C.14.1 CATEGORY AND NUMBER OF ANIMALS (Column A and B)

The most detailed agricultural statistics of Norway are for the year 1989, these are used throughout (Statistisk Sentralbyrå, 1992). Animal categories used in these statistics do not completely coincide with those used in the spreadsheet.

In the Norwegian statistics, cattle are divided into 2 groups: cows and other cattle. It assumed that a 10% of other cattle together with cows form the cattle > 2 years category; 1/3 of the remaining "other cattle" fall into the 1-2 years category, the rest are calves.

In Norwegian statistics pigs are divided into 2 groups: pigs for breeding and other pigs. The first group forms the boars and sows category in the spreadsheet. Approximately 2/3 of other pigs are pigs for slaughter. The rest are assumed to be piglets which are fed together with the sow. The manure production of the sows includes that of dependent piglets.

National agricultural statistics only count horses on farms (approximately 17,000). An unknown but substantial number of private horses are not registered. The riding society has 3,137 horses listed for competitions. Our estimate of 20,000 may still be low.

Poultry are divided into 3 groups according to national statistics: hens, hens and chickens, and broilers. The first 2 groups are combined to form the laying hens category in the spreadsheet. The latter one is used for table fowl.

C.14.2 CALCULATION FACTORS

C.14.2.1 Inside Winter and Summer (Column C and D)

Cattle

In Norway dairy cattle are stabled for approximately 8 months (0.67 years). In summer, dairy cattle are stabled during the night. This gives a period 0.15 years. The period 0.67 years is also used for yearlings, whereas the period 0.75 years is used for calves (the Dutch factor is used). The factor indoors on a summer diet is taken as 0.

Sheep, Goats and Equine Animals

Sheep are grazing 4 months/year. It is assumed that the same is true for goats. Most horses will be outside at least part of the time, more so in summer than in winter. This corresponds with a period 0.65 years inside.

C.14.2.2 Nitrogen Excretion in Summer and Winter

An estimated ratio 1.1 is used, as pasture fertilisation rates are less than those in the Netherlands.

C.14.3 EMISSION FACTORS

C.14.3.1 Animal Houses in Winter and Summer (Column F and G)

The same procedure as described under the Netherlands was used to calculate the NH_3 emission from cattle, sheep, goats and equine houses. This may be an overestimate, because the average year temperature is lower in Norway than in the Netherlands. Manure is generally stored below the shed floor.

For pigs UK shed emissions factors are used (no correction for outdoor storage apply), pigs for slaughter: 0.00618 kg NH_3-N/hd/day and boars and sows: 0.00618 x 33/12.8 = 0.1593 kg NH_3-N/hd/day (Section C.5.3.1).

These values are also used for Sweden and Finland.

C.14.3.2 Spreading (Column I)

Dutch spreading factor for NH_3 emission following manure spreading are used (Section 3.2.2).

Table C.19: Norway 1989

	A	B	C	D	E	F	G	H	I
	Category		Calculation factors			Emission factors			
	Animals	Number of animals (x1000)	Inside winter (y)	Inside summer (y)	N excretion ratio summer/ winter	Animal houses winter (kg N/ hd/d)	Animal houses summer (kg N/ hd/d)	Grazing, N loss/N excreted	Spreading N loss/N applied
11	Total cattle	949							
12	> 2 y	401	0.67	0.15	1.10	0.01659	0.03524	0.080	0.285
13	1-2 y	169	0.67	0.00	1.10	0.01501	0.03189	0.080	0.285
14	< 1 y	339	0.75	0.00	1.10	0.00652	0.01385	0.080	0.285
16	Total pigs	657							
17	Pigs for slaugther	382	1.00			0.00618	0.00618		0.285
18	Boars and sows	85	1.00			0.01593	0.01593		0.285
20	Total sheep	2,183	0.65	0.00	1.10	0.00395	0.00839	0.046	0.285
22	Total goats	94	0.65	0.00	1.10	0.00395	0.00839	0.046	0.285
24	Equine	20	0.65	0.00	1.00	0.00988	0.02098	0.080	0.285
26	Total poultry	9,086							
27	Laying hens	4,649	1.00			0.00019	0.00019		0.376
28	Table fowl	4,437	1.00			0.00015	0.00015		0.072
30									
34	**Fertilisers**								Emission factor
36	Urea								0.150
37	Ammonium nitrate								0.010
38	Ammonium phosphate								0.050
39	Ammonium sulphate								0.050
40	Other								0.000
42									
45	**Industry**								
46	**Crops**								
47	**Miscellaneous**								
49									

Table C.19: Norway 1989 (cont.)

J	K	L	M	N	O	P	Q	R	S	T
N Excretion					NH_3-N emissions					
Total (kg N/ hd/y)	Within animal house (kg N/ hd/y)	Outside animal house (kg N/ hd/y)	Total (kt N)	Total in slurry (kt N)	Animal houses (kt N)	Surface spreading (kt N)	Grazing (kt N)	Total (kt N)	% of N excreted	% per category
										41.9
84	67.90	16.10	34	25	2.4	7.1	0.5	10.0	29.7	
76	49.29	26.71	13	8	0.6	2.2	0.4	3.2	24.8	
33	24.15	8.85	11	8	0.6	2.2	0.2	3.0	26.9	
										8.2
12.8	12.80	0.00	5	4	0.9	1.1		2.0	41.1	
33	33.00	0.00	3	2	0.5	0.7		1.2	41.1	
20	12.56	7.44	44	25	2.1	7.2	0.7	10.1	23.1	26.2
20	12.56	7.44	2	1	0.1	0.3	0.0	0.4	23.1	1.1
50	32.50	17.50	1	1	0.0	0.2	0.0	0.2	24.8	0.6
										4.9
0.766	0.766	0.00	4	3	0.3	1.2		1.5	43.2	
0.348	0.348	0.00	2	1	0.2	0.1		0.3	21.8	
		Subtotal	**117**	**78**	**8**	**22**	**2**	**32**	**27**	**82.9**
			Fertiliser use (kt N)					NH_3-N losses (kt N)		
				0.6				0.1		
				102.2				1.0		
				0.0				0.0		
				0.0				0.0		
				7.6				0.0		
			Subtotal	**110.4**				1.1	1.0	2.9
								0.9		2.3
								1.5		3.9
								3.1		8.0
							Total	**38.6**		**100.0**

C.15 SWEDEN (Table C.20)

C.15.1 CATEGORY AND NUMBER OF ANIMALS (Column A and B)

The number of animals in 1990, used in the spreadsheet, is taken from the agricultural statistics yearbook of Sweden (SCB, 1991b). The animal distribution is very uneven, most cattle and pigs are in the southern part of the country.

Swedish statistics divide cattle into 3 groups: cows, heifers, bulls and steers 1 year of age and older, and calves younger than 1 year. The number of animals in the cattle > 2 years category in the spreadsheet is calculated by adding the number of cows and 1/3 of the number of heifers, bulls and steers 1 year of age and older. The number of animals in the cattle 1-2 year category in the spreadsheet is set equal to 2/3 of the number of heifers, bulls and steers 1 year and older. The number of calves younger than 1 year, is used as the number of animals in the cattle < 1 year category in the spreadsheet.

Pigs are divided into 2 groups in Swedish statistics: boars, sows and other pigs younger or older than 3 months. From the statistics pigs for slaughter are taken as 1/3 of the pigs younger than 3 months and pigs older than 3 months. 2/3 of the group younger than 3 months are assumed to be piglets.

Horses no longer appear in Swedish agricultural statistics, but riding has developed into a highly popular sport and the estimate of 170,000 horses may still be low.

Poultry appear under heading: laying hens, chickens or laying hens, and chicken for slaughter. The first 2 groups are considered as laying hens and the latter as table fowl.

C.15.2 CALCULATION FACTORS

C.15.2.1 Inside Winter and Summer (Column C and D)

Cattle

In Sweden, dairy cattle are stabled for 7.5 months (0.625 years). It is prohibited to keep cattle stabled all year. In summer, dairy cattle are stabled during the night. This gives a period of 0.15 years for inside summer. This factor is also used for yearlings whereas the Dutch period 0.75 years is used for calves.

Sheep, Goats and Equine Animals

Sheep are grazing 4 months/year. It is assumed that the same is true for horses and goats. During the rest of the year they are inside (0.65 years).

C.15.2.2 Nitrogen Excretion in Summer and Winter

As a best estimate a ratio 1.1 is used.

C.15.3 EMISSION FACTORS

C.15.3.1 Animal Houses in Winter and Summer (Column F and G)

The same procedure as described under the Netherlands was used to calculate the NH_3 emission from cattle, sheep, goats equine and poultry houses. This may be an overestimate, because the average year temperature is lower in Sweden than in the Netherlands. For pigs UK values (excluding outside storage losses) as described for Norway were used.

C.15.3.2 Spreading (Column I)

Dutch factors for NH_3 emission following manure spreading are used (Section C.3.2.2).

Table C.20: Sweden 1990

	A	B	C	D	E	F	G	H	I
	Category		Calculation factors			Emission factors			
	Animals	Number of animals (x1000)	Inside winter (y)	Inside summer (y)	N excretion ratio summer/ winter	Animal houses winter (kg N/ hd/d)	Animal houses summer (kg N/ hd/d)	Grazing, N loss/N excreted	Spreading N loss/N applied
11	Total cattle	1,718							
12	> 2 y	830	0.63	0.15	1.10	0.02213	0.04699	0.080	0.285
13	1-2 y	362	0.63	0.00	1.10	0.01501	0.03189	0.080	0.285
14	< 1 y	524	0.75	0.00	1.10	0.00652	0.01385	0.080	0.285
16	Total pigs	2,264							
17	Pigs for slaugther	1,361	1.00			0.00618	0.00618		0.285
18	Boars and sows	230	1.00			0.01593	0.01593		0.285
20	Total sheep	406	0.65	0.00	1.10	0.00395	0.00839	0.046	0.285
22	Total goats	5	0.65	0.00	1.10	0.00395	0.00839	0.046	0.285
24	Equine	170	0.65	0.00	1.10	0.00988	0.02098	0.080	0.285
26	Total poultry	11,311							
27	Laying hens	6,392	1.00			0.00019	0.00019		0.376
28	Table fowl	4,920	1.00			0.00015	0.00015		0.072
30									
34	**Fertilisers**								Emission factor
36	Urea								0.150
37	Ammonium nitrate								0.010
38	Ammonium phosphate								0.050
39	Ammonium sulphate								0.050
40	Other								0.000
42									
45	**Industry**								
46	**Crops**								
47	**Miscellaneous**								
49									

Table C.20: Sweden 1990 (cont.)

J	K	L	M	N	O	P	Q	R	S	T
N Excretion					NH_3-N emissions					
Total (kg N/ hd/y)	Within animal house (kg N/ hd/y)	Outside animal house (kg N/ hd/y)	Total (kt N)	Total in slurry (kt N)	Animal houses (kt N)	Surface spreading (kt N)	Grazing (kt N)	Total (kt N)	% of N excreted	% per category
										55.9
112	85.28	26.72	93	64	6.3	18.4	1.8	26.5	28.5	
76	45.78	30.22	28	15	1.2	4.4	0.9	6.5	23.6	
33	24.15	8.85	17	12	0.9	3.3	0.4	4.6	26.9	
										15.3
12.8	12.80	0.00	17	14	3.1	4.1		7.2	41.1	
33	33.00	0.00	8	6	1.3	1.8		3.1	41.1	
20	12.56	7.44	8	5	0.4	1.3	0.1	1.9	23.1	2.8
20	12.56	7.44	0	0	0.0	0.0	0.0	0.0	23.1	0.0
50	31.40	18.60	9	5	0.4	1.4	0.3	2.1	24.3	3.1
										3.7
0.766	0.766	0.00	5	4	0.4	1.7		2.1	43.2	
0.348	0.348	0.00	2	1	0.3	0.1		0.4	21.8	
		Subtotal	**186**	**128**	**14**	**36**	**3**	**54**	**29**	**80.8**
			Fertiliser use (kt N)					NH_3-N losses (kt N)		
				4.2				0.6		
				156.5				1.6		
				0.0				0.0		
				0.0				0.0		
				73.6				0.0		
			Subtotal	**234.3**				2.2	0.9	**3.3**
								0.3		0.4
								5.1		7.6
								5.4		8.0
							Total	**67.3**		**100.0**

C.16 FINLAND (Table C.21)

C.16.1 CATEGORY AND NUMBER OF ANIMALS (Column A and B)

Numbers of animals are taken from the yearbook of farm statistics of Finland (Maatilahallitus, 1991).

Cattle are divided into 7 groups in Finnish statistics: dairy cows, bulls, beef cows, young bulls, heifers, heifers for beef cows and calves. The first 3 groups are allocated to cattle > 2 years. The fourth, fifth and sixth group is allocated to the cattle between 1-2 year category. The last group corresponds with the cattle < 1 year.

The Finnish category of pigs are divided into 3 groups: over 6 months, between 2-6 months and under 2 months. The first group forms the boars and sows category and the second one the pigs for slaughter category in the spreadsheet. The number of pigs under 2 months is discounted as it is assumed that these are piglets fed by the sow. The manure production of the sows includes that of dependent piglets. Goats are not listed in Finnish statistics.

Poultry, excluding broilers, are divided into 2 groups in Finnish statistics: hens 6 months and over and chickens under 6 months. These 2 groups together form the laying hens category in the spreadsheet. However, in the Yearbook no numbers of table fowl are given. Therefore the ratio between laying hens and table fowl of Norway is used to estimate the number of table fowl for Finland.

Fur animals are a significant source of NH_3 emissions in Finland (Pipatti, 1992) but as discussed in Section C.2.1.2 emissions from fur animals are regarded as included with miscellaneous emissions.

C.16.2 CALCULATION FACTORS

C.16.2.1 Inside Winter and Summer (Column C and D)

Cattle

In Finland dairy cattle are mostly stabled for 8 months (0.67 years). In summer, dairy cattle is stabled during the night (0.15 years). The period 0.67 years is also used for yearlings and calves.

Sheep, Goats and Equine Animals

Sheep are grazing 4 months/year. It is assume that the same is true for horses and goats. They are inside during the rest of the year (0.65 years)

C.16.2.2 Nitrogen Excretion in Summer and Winter (Column E)

The ratio 1.1 is used.

C.16.3 EMISSION FACTORS

C.16.3.1 Animal Houses in Winter and Summer (Column F and G)

The same procedure as described under the Netherlands was used to calculate the NH_3 emission from cattle, sheep, goats and equine houses. This may be an overestimate, because the average year temperature is lower in Finland than in the Netherlands. For pigs UK values (excluding storage losses) as described for Norway were used.

C.16.3.2 Spreading (Column I)

Approximately 50% of the slurry is spread in spring, most of the rest in autumn, before ploughing. A minor amount is still spread on frozen soil in wintertime.

For slurry spreading Dutch values are used, as for other nordic countries.

Table C.21: Finland 1990

	A	B	C	D	E	F	G	H	I
	Category		Calculation factors			Emission factors			
	Animals	Number of animals (x1000)	Inside winter (y)	Inside summer (y)	N excretion ratio summer/ winter	Animal houses winter (kg N/ hd/d)	Animal houses summer (kg N/ hd/d)	Grazing, N loss/N excreted	Spreading N loss/N applied
11	Total cattle	1,357							
12	> 2 y	515	0.67	0.15	1.10	0.02094	0.04448	0.080	0.285
13	1-2 y	357	0.67	0.00	1.10	0.01501	0.03189	0.080	0.285
14	< 1 y	485	0.67	0.00	1.10	0.00652	0.01385	0.080	0.285
16	Total pigs	1,298							
17	Pigs for slaugther	524	1.00			0.00618	0.00618		0.285
18	Boars and sows	236	1.00			0.01593	0.01593		0.285
20	Total sheep	107	0.65	0.00	1.10	0.00395	0.00839	0.046	0.285
22	Total goats	0	0.65	0.00	1.10	0.00395	0.00839	0.046	0.285
24	Equine	44	0.65	0.00	1.10	0.00988	0.02098	0.080	0.285
26	Total poultry	10,404							
27	Laying hens	6,138	1.00			0.00019	0.00019		0.376
28	Table fowl	4,266	1.00			0.00015	0.00015		0.072
30									
34	**Fertilisers**								Emission factor
36	Urea								0.150
37	Ammonium nitrate								0.010
38	Ammonium phosphate								0.050
39	Ammonium sulphate								0.050
40	Other								0.000
42									
45	**Industry**								
46	**Crops**								
47	**Miscellaneous**								
49									

Table C.21: Finland 1990 (cont.)

J	K	L	M	N	O	P	Q	R	S	T
N Excretion					NH_3-N emissions					
Total (kg N/ hd/y)	Within animal house (kg N/ hd/y)	Outside animal house (kg N/ hd/y)	Total (kt N)	Total in slurry (kt N)	Animal houses (kt N)	Surface spreading (kt N)	Grazing (kt N)	Total (kt N)	% of N excreted	% per category
										56.9
106	85.68	20.32	55	40	3.9	11.5	0.8	16.2	29.7	
76	49.29	26.71	27	16	1.3	4.6	0.8	6.7	24.8	
33	21.40	11.60	16	10	0.8	2.7	0.4	4.0	24.8	
										12.6
12.8	12.80	0.00	7	6	1.2	1.6		2.8	41.1	
33	33.00	0.00	8	6	1.4	1.8		3.2	41.1	
20	12.56	7.44	2	1	0.1	0.4	0.0	0.5	23.1	1.0
20	12.56	7.44	0	0	0.0	0.0	0.0	0.0	0.0	0.0
50	31.40	18.60	2	1	0.1	0.4	0.1	0.5	24.3	1.1
										5.0
0.766	0.766	0.00	5	4	0.4	1.6		2.0	43.2	
0.348	0.348	0.00	1	1	0.2	0.1		0.3	21.8	
		Subtotal	**123**	**86**	**9**	**25**	**2**	**36**	**30**	**76.6**
			Fertiliser use (kt N)					NH_3-N losses (kt N)		
				2.9				0.4		
				228.1				2.3		
				0.0				0.0		
				0.0				0.0		
				0.3				0.0		
			Subtotal	**231.3**				2.7	1.2	5.7
								0.7		1.4
								3.9		8.3
								3.8		8.0
							Total	**47.3**		**100.0**

C.17 AUSTRIA (Table C.22)

C.17.1 CATEGORY AND NUMBER OF ANIMALS (Column A and B)

The number of animals in 1990 was provided by BASF Austria.

C.17.2 CALCULATION FACTORS

C.17.2.1 Inside Winter and Summer (Columns C and D)

Cattle

It is assumed that in Austria the cattle are kept indoors part of the year and 0.65 years is used as the period for indoors on a winter diet and 0.1 years for indoors on a summer diet. Both values are estimates. For yearlings a period 0.65 years is used for indoors on a winter diet and 0.1 years as the factor for indoors on a summer diet. For calves these periods are 0.75 years and 0.

C.17.2.2 Nitrogen Excretion in Summer and Winter (Column E)

As a best estimate 1.1 is used.

C.17.3 EMISSION FACTORS

C.17.3.1 Animal Houses in Winter and Summer (Column F and G)

The same procedure as described under the Netherlands was used to calculate the NH_3 emission from cattle, sheep, goats and equine houses. German emission factors are used for pigs and poultry.

C.17.4.2 Spreading (Column I)

German emission factors are used (Section C.4.3.2).

Table C.22: Austria 1990

	A	B	C	D	E	F	G	H	I
	Category		Calculation factors			Emission factors			
	Animals	Number of animals (x1000)	Inside winter (y)	Inside summer (y)	N excretion ratio summer/ winter	Animal houses winter (kg N/ hd/d)	Animal houses summer (kg N/ hd/d)	Grazing, N loss/N excreted	Spreading N loss/N applied
11	Total cattle	2,401							
12	> 2 y	1,048	0.65	0.10	1.10	0.04071	0.06153	0.080	0.220
13	1-2 y	521	0.65	0.00	1.10	0.03363	0.05083	0.080	0.220
14	< 1 y	832	0.75	0.00	1.10	0.01469	0.02216	0.080	0.220
16	Total pigs	3,720							
17	Pigs for	2,196	1.00			0.00716	0.00716		0.140
18	slaugther	375	1.00			0.01846	0.01846		0.140
	Boars and sows								
20	Total sheep	234	0.50	0.00	1.10	0.00395	0.00839	0.046	0.220
22	Total goats	39	0.50	0.00	1.10	0.00395	0.00839	0.046	0.220
24	Equine	61	0.50	0.00	1.10	0.00988	0.02098	0.080	0.220
26	Total poultry	12,872							
27	Laying hens	6,338	1.00			0.00030	0.00030		0.376
28	Table fowl	6,534	1.00			0.00039	0.00039		0.072
30									
34	**Fertilisers**								Emission factor
36	Urea								0.150
37	Ammonium nitrate								0.010
38	Ammonium phosphate								0.050
39	Ammonium sulphate								0.050
40	Other								0.000
42									
45	**Industry**								
46	**Crops**								
47	**Miscellaneous**								
49									

Table C.22: Austria 1990 (cont.)

J	K	L	M	N	O	P	Q	R	S	T
N Excretion					NH_3-N emissions					
Total (kg N/ hd/y)	Within animal house (kg N/ hd/y)	Outside animal house (kg N/ hd/y)	Total (kt N)	Total in slurry (kt N)	Animal houses (kt N)	Surface spreading (kt N)	Grazing (kt N)	Total (kt N)	% of N excreted	% per category
										59.3
92	67.56	24.44	96	58	12.5	12.8	2.0	27.4	28.4	
76	47.73	28.27	40	21	4.2	4.6	1.2	9.9	25.0	
33	24.15	8.85	27	17	3.3	3.7	0.6	7.6	27.7	
										16.9
12.8	12.80	0.00	28	22	5.7	3.1		8.9	31.6	
33	33.00	0.00	12	10	2.5	1.4		3.9	31.6	
20	9.52	10.48	5	2	0.2	0.5	0.1	0.7	15.9	1.0
20	9.52	10.48	1	0	0.0	0.1	0.0	0.1	15.9	0.2
50	23.81	26.19	3	1	0.1	0.3	0.1	0.5	17.6	0.7
										4.3
0.766	0.766	0.00	5	4	0.7	1.6		2.3	46.5	
0.348	0.348	0.00	2	1	0.9	0.1		1.1	45.2	
		Subtotal	**220**	**137**	**30**	**28**	**4**	**62**	**28**	**82.4**
			Fertiliser use (kt N)				NH_3-N losses (kt N)			
				1.7				0.3		
				120.8				1.2		
				2.3				0.1		
				0.2				0.0		
				0.1						
			Subtotal	**125.1**				**1.6**	**1.3**	**2.1**
								0.4		0.5
								5.3		7.0
								6.1		8.0
							Total	**75.7**		**100.0**

C.18 SWITZERLAND (Table C.23)

C.18.1 CATEGORY AND NUMBER OF ANIMALS (Column A and B)

The number of animals in 1990 is taken from the Bundesamt für Statistik (1992).

The number of cattle > 2 years is calculated from Swiss statistics by subtracting the number of animals in the cattle < 1 year and cattle between 1-2 years categories from the total number of animals.

The number of pigs of less than 30 kg is not given separately in Swiss statistics, because these young pigs are fed together with the sows. For EEC countries this is done for pigs of less than 20 kg. Therefore, one third of the pigs less than 30 kg are added to the category pigs for slaughter.

C.18.2 CALCULATION FACTORS

The calculation factors are based on the report of Menzi *et al* (1992) on special conditions influencing ammonia emissions factors in Switzerland.

C.18.2.1 Inside Winter and Summer (Column C and D)

Cattle

According to Menzi *et al* (1992) about two thirds of the dairy cows in Switzerland are grazed during summer. On average these grazed cows spend about 10 hours/day on the pasture for 150-220 days. The fraction of the year that cows are outside can be calculated as: 2/3 x 0.5 x ((150 + 220)/365) x 10/24 = 0.14.

This corresponds to a fraction "inside on a winter diet" of 0.66.

The fraction of the year that cattle is inside on a summer diet is calculated as: 2/3 x 0.5 x ((150 + 220)/365) x 14/24 = 0.20

It is assumed that these numbers also hold for yearlings and calves.

C.18.2.2 Nitrogen Excretion in Summer and Winter (Column E)

According to Menzi *et al* (1992) the N excretion of a cow with a winter and summer ration is respectively 6.2 and 8.6 kg N/month. This correspond to a ratio of 1.4. This factor is also used for yearlings and calves. For equine, sheep and goats a factor 1.1 is used.

C.18.3 EMISSION FACTORS

C.18.3.1 Animal Houses in Winter and Summer (Columns F and G)

In Switzerland both solid manure production and slurry production are common systems. Manure and slurry is generally stored outdoors. The slurry is mostly stored in an open pit. On average it is assumed that a 10% loss from storage is appropriate. According to Menzi *et al* (1992) about 50% of the cows in Switzerland are kept in stables where solid manure and urine-rich slurry or liquid manure (urine, part of faeces) are separated. Very little is known about NH_3 emission from such stables. As a best estimate the Dutch emission factors are used. For the other animal categories German factors are adopted.

C.18.3.2 Spreading (Column I)

In Switzerland it is common practice to have pigs and cattle in the same farm. Generally, pig slurry and cattle slurry is stored in the same pit.

The slurry is generally diluted with water in a ratio of 1:1 or higher. This can reduce emission by up to 50% (Bussink and Bruins, 1992).

Therefore the Dutch emission factors are used corrected for dilution, which results in 0.5x0.285=0.14. This factor is used for all animal categories, except for poultry where the Dutch values are used.

C.18.4 N Excretion

C.18.4.1 Total Nitrogen Excreted per Animal (Column J)

The same factors as for the Netherlands are used, except for dairy cattle where the N excretion is calculated based on milk production.

For sheep the standard of 20 kg N/a/year is used.

Table C.23: Switzerland 1990

	A	B	C	D	E	F	G	H	I
	Category		Calculation factors			Emission factors			
	Animals	Number of animals (x1000)	Inside winter (y)	Inside summer (y)	N excretion ratio summer/ winter	Animal houses winter (kg N/ hd/d)	Animal houses summer (kg N/ hd/d)	Grazing, N loss/N excreted	Spreading N loss/N applied
11	Total cattle	1,865							
12	> 2 y	952	0.66	0.20	1.40	0.04617	0.07852	0.080	0.140
13	1-2 y	286	0.66	0.20	1.40	0.03190	0.05245	0.080	0.140
14	< 1 y	627	0.66	0.20	1.40	0.01385	0.02356	0.080	0.140
16	Total pigs	1,789							
17	Pigs for slaugther	1,121	1.00			0.00716	0.00716		0.140
18	Boars and sows	191	1.00			0.01846	0.01846		0.140
20	Total sheep	253	0.50	0.00	1.10	0.00395	0.00839	0.046	0.140
22	Total goats	47	0.50	0.00	1.10	0.00395	0.00839	0.046	0.140
24	Equine	48	0.50	0.00	1.10	0.00988	0.02098	0.080	0.140
26	Total poultry	6,529							
27	Laying hens	2,819	1.00			0.00030	0.00030		0.376
28	Table fowl	3,719	1.00			0.00039	0.00039		0.072
30									
34	**Fertilisers**								Emission factor
36	Urea								0.150
37	Ammonium nitrate								0.010
38	Ammonium phosphate								0.050
39	Ammonium sulphate								0.100
40	Other								0.000
42									
45	**Industry**								
46	**Crops**								
47	**Miscellaneous**								
49									

Table C.23: Switzerland 1990 (cont.)

J	K	L	M	N	O	P	Q	R	S	T
N Excretion					NH_3-N emissions					
Total (kg N/ hd/y)	Within animal house (kg N/ hd/y)	Outside animal house (kg N/ hd/y)	Total (kt N)	Total in slurry (kt N)	Animal houses (kt N)	Surface spreading (kt N)	Grazing (kt N)	Total (kt N)	% of N excreted	% per category
										65.5
110	91.10	18.90	105	71	16.0	9.9	1.4	27.4	26.1	
76	62.94	13.06	22	15	3.3	2.1	0.3	5.7	26.1	
33	27.33	5.67	21	14	3.2	2.0	0.3	5.4	26.1	
										11.1
12.8	12.80	0.00	14	11	2.9	1.6		4.5	31.6	
33	33.00	0.00	6	5	1.3	0.7		2.0	31.6	
20	9.52	10.48	5	2	0.2	0.3	0.1	0.6	12.4	1.1
20	9.52	10.48	1	0	0.0	0.1	0.0	0.1	12.4	0.2
50	23.81	26.19	2	1	0.1	0.1	0.1	0.3	14.1	0.6
										2.7
0.766	0.766	0.00	2	2	0.3	0.7		1.0	46.5	
0.348	0.348	0.00	1	1	0.5	0.1		0.6	45.2	
		Subtotal	**180**	**122**	**28**	**17**	**2**	**48**	**27**	**81.1**
			Fertiliser use (kt N)					NH_3-N losses (kt N)		
				17.0				2.6		
				48.1				0.5		
				1.9				0.1		
				2.5				0.3		
				0.7				0.0		
			Subtotal	**70.2**				3.4	4.8	5.7
								0.0		0.1
								3.0		5.1
								4.7		8.0
							Total	**58.8**		**100.0**

C.19 NH_3 EMISSIONS FROM WESTERN EUROPEAN AGRICULTURE: AN OVERVIEW

The results from the various countries are summarised in Table C.24.

This table in abbreviated form is presented in the main text, Table 12.

Table C.24: Summary

	Total excreted N (kt)	Total N in slurry (kt)	NH_3-N emission (kt)				Loss (% of N excreted)	Fertiliser NH_3-N losses (kt)	Industry (kt)	Crops (kt)	Miscellaneous (kt)	Arable and grassland (1000 ha)[a]	NH_3-N loss (kg/ha arable or grassland)	Total Losses (kt)
			Stables	Surface spreading	Grazing	Total								
Austria	220	137	30	28	4	62	28	1.6	0.4	5.3	6.1	3,548	21.3	76
Belgium/ Luxembourg	343	216	29	61	8	99	29	4.2	1.1	2.3	9.2	1,504	76.7	115
Denmark	308	217	31	62	5	97	32	7.5	0.4	4.2	9.5	2,774	42.9	119
Finland	123	86	9	25	2	36	30	2.7	0.7	3.9	3.8	2,576	18.3	47
France	2,196	1,069	285	216	63	564	26	127.6	2.0	46.1	64.3	30,717	26.2	804
Greece	408	82	25	18	14	57	14	18.6	0.5	13.8	7.8	9,179	10.7	98
Ireland	602	201	44	55	25	124	21	12.5	0.8	8.5	12.6	5,643	28.0	158
Italy	1,036	603	251	131	9	390	38	64.0	3.3	21.0	41.6	16,910	30.8	520
Netherlands	718	437	60	124	16	200	28	8.5	3.6	3.0	18.7	2,004	116.8	234
Norway	117	78	8	22	2	32	27	1.1	0.9	1.5	3.1	989	39.0	39
Portugal	237	88	34	18	7	59	25	6.2	0.1	6.8	6.2	4,532	17.2	78
Spain	1,222	388	157	77	36	270	22	96.1	1.8	45.8	35.9	30,555	14.7	449
Sweden	186	128	14	36	3	54	29	2.2	0.3	5.1	5.4	3,411	19.7	67
Switzerland	180	122	28	17	2	48	27	3.4	0.0	3.0	4.7	2,021	29.1	59
United Kingdom	1,901	623	136	161	69	366	19	55.9	1.4	26.9	39.1	17,933	27.3	489
Germany	1,901	1,051	245	212	46	504	27	78.4	1.5	27.1	53.1	18,056	36.8	664
Totals	**11,698**	**5,526**	**1,387**	**1,264**	**310**	**2,961**	**25**	**490**	**19**	**224**	**321**	**15,2352**	**26.4**	**4,016**

a Based on page 10-13 of the FAO yearbook 1990 (arable and permanent crops and permanent pasture)

C.20 SENSITIVITY ANALYSIS

While the number of animals, agricultural areas, and the amount and type of fertiliser applied are known with great accuracy, emission factors remain estimates because of the limited number of experiments. Therefore the emission for each country represents only the most probable value within a certain range. It is the purpose of this sensitivity analysis to estimate this range of uncertainty. The Dutch data (Table C.7) are used as basis for the estimated errors (Table C.25).

Table C.25: Netherlands 1990 - Estimated Errors (±) in Emission and Calculation Factors Used

	A	B	C	D	E	F	G	H	I	J
	Category		Calculation factors			Emission factors				N Excretion
	Animals	Number (x1000)	Inside winter ration	Inside summer ration	N excretion ratio summer/ winter	Animal houses winter (kg N/hd/d)	Animal houses summer (kg/hd/d)	Grazing, N excreted (%)	Spreading N loss/N applied	Total (kg/a/y)
115	Total cattle	4,830								
116	> 2 y	2,171	0.2	-0.20	0.12	0.1	0.2	0.2	0.1	0.10
117	1 y - 2 y	964	0.2	0.00	0.12	0.1	0.2	0.2	0.1	0.20
118	<1 y	1,695	0.2	0.00	0.12	0.1	0.2	0.2	0.1	0.20
120	Total pigs	13,788								
121	Pigs for slaugther	7,746				0.1	0.1		0.1	0.10
122	Boars and sows	1,299				0.1	0.1		0.1	0.10
124	Total sheep	1,870	0.5	0.00	0.12	0.4	0.4	0.2	0.1	0.20
126	Total goats	77	0.5	0.00	0.12	0.4	0.4	0.2	0.1	0.20
128	Equine	185	0.2	0.00	0.12	0.4	0.4	0.2	0.1	0.20
130	Total poultry	92,765								
131	Laying hens	51,593				0.3	0.3		0.2	0.15
132	Table fowl	41,172				0.3	0.3		0.2	0.15
	Fertilisers								Emission factor	
140	Urea								0.3	
141	CAN (AN, etc.)								0.3	
142	AP								0.3	
143	$(NH_4)_2SO_4$								0.3	
144	Other								0.3	
146										
149	**Industry**									0.1
150	**Crops**									0.5
151	**Miscellaneous**									0.4

C.20.1 NUMBER OF ANIMALS (Column B)

The error in the number of animals should be small and is here assumed to be 0.

C.20.2 CALCULATION FACTORS

C.20.2.1 Inside Winter and Summer (Column C and D)

The annual period that cows are kept indoors and are fed a winter diet may vary from year to year. The average value of 0.5 may vary between 0.4 and 0.6, giving a variation of 20%. This percentage is also used for calves, yearlings goats and equine animals.

The period of the year that sheep are indoors may vary from 0.1 to 0.3, giving a variation of 50%.

Column C is not relevant for pigs and poultry.

Column D is only relevant for cows. The part of the year indoors on a summer diet is related to the time indoors on a winter diet. If the proportion indoors on a winter diet increases then the part of the year indoors on a summer diet decreases correspondingly.

C.20.2.2 Nitrogen Excretion in Summer and Winter (Column E)

Column E is only relevant for grazing animals. This ratio may vary due to weather conditions dressing rate, or diet. At higher N rates applied to grassland the N content of grass increases (Bussink, 1994). The result is that the ratio of N excretion in summer and winter increases since the diet of cows generally contains more grass/grass silage in summer than in winter. From data of Coppoolse *et al* (1990) and Mandersloot (1992) it can be calculated that the ratio can vary between 1.10 to 1.40. Therefore a factor 140-110/140+110 = 0.12 is used in Column E for the grazing animals. It is assumed that it can vary by a factor 0.1.

C.20.3 EMISSION FACTORS

C.20.3.1 Animal Houses in Winter and Summer (Column F and G)

Cattle

Oosthoek *et al* (1990), reports that for cattle the variation in emission per month was less than 10% (Section C.3.2.1). For a whole population there will be more variation in the diet and its N content

than in this study. Therefore the total variation is assumed to be 10% in winter. It is expected that the variation in summer is greater because measurements took only place in April and May. Therefore, we use 20% for the summer. The same value is used for yearlings and calves (Oosthoek *et al*, 1990). In contrast pigs showed almost no variation in emission for different animal house types, though there were some differences between individual measurement periods during the season. The variation in emission is assumed to be 10%.

Sheep, Goats and Equine Animals

For sheep, goats and equine animals, no measured emission data are known. The housing of these animals differs also from that of cows, but there is not much differences between fertiliser application rates for sheep and cow pastures. The uncertainty attached to estimated data for these animals greater than that for cows. A variation of 40% is assumed.

Poultry

Emission data for table fowl (Kroodsma, 1989) show a large variation between individual measuring periods. A variation of 30% is assumed on the basis of these data. For laying hens few emission data are known and the same value as for table fowl is used.

C.20.3.2 Grazing (Column H)

This column is only relevant for cattle, sheep, goats and equine animals. In the UK (Jarvis *et al* 1989a,b) and in the Netherlands, variation in emissions was large between measurement periods within a season but only small between season. Emissions also vary greatly with fertiliser input. The latter is taken into account (as well as possible) for the Netherlands. The overall uncertainty in the value of 0.08 used is assumed to be plus or minus 20%, based on observed data variation by Vertregt and Rutgers (1991) and Bussink (1992, 1994). This value is also used for the other grazing animals, except for sheep and goats. As we have little information for these categories, we assume an error of 50%.

C.20.3.3 Spreading (Column I)

Emission measurements in the Netherlands with pig and cattle slurry showed that the emission may vary between the extremes of 20 and 100% of the NH_4^+-N applied (Bruins and Huijsmans, (1989); Bussink and Klarenbeek (1990); Bussink and Bruins (1992) and Van der Molen *et al* (1989, 1990). The results centres around 60%. Hence this factor has a variation of 10%. On average emissions

were 0.285 of the total N-applied. This percentage is used for cattle, pigs, goats, sheep and equine animals. For poultry manure fewer data are known. The variation is therefore assumed to be 20%.

C.20.4 NITROGEN EXCRETION

C.20.4.1 Total Nitrogen Excreted Per Animal (Column J)

Cattle

Mandersloot *et al* (1992) showed that the N excretion of cows could vary between 101 and 140 kg for a cow with a milk yield of 6,000 kg/year, so it is assumed that total N excretion varies by 20%. Since the pasture of sheep and goats is similar in N content to that of cows the same variation (20%) is assumed also for the other grazing animals.

Pigs

In the Netherlands diets for pigs show only minor variations. Therefore a variation in N excretion of 10% is assumed, as indicated by the data of Coppoolse *et al* (1990).

Poultry

The N intake of laying hens depends on their weight. In the Netherlands N-intake can easily vary 15% (Coppoolse *et al*, 1990). This percentage is used for laying hens and for table fowl.

C.20.5 EMISSIONS FROM FERTILISER APPLICATION

It is known that NH_3 volatilisation from applied fertilisers can vary, depending on weather and soil conditions. Variations of up to 30% are not unlikely.

C.20.6 EMISSIONS FROM INDUSTRY, CROPS AND MISCELLANEOUS SOURCES

The industrial emissions are probably within ±10% of the true value. As the data refer to 1988 and there have been plant closures since then, the estimate given is more likely to be an over- than an under-estimate. The crop areas are accurate but the emissions are of an unknown accuracy, perhaps around 50%. 8% of total sources was selected as emission factor for miscellaneous emissions, because the discussion (Section 3.5) indicated that these emissions were within the range of 5 to 10% of other combined emission. The accuracy should be about 40%.

C.20.7 MINIMUM AND MAXIMUM EMISSIONS

All the variations described above are used to calculate minimum and maximum values for the numbers in spreadsheet Columns B to J (Table C.26 and C.27). Calculations using these extreme values gives for the Netherlands an overall minimum and maximum emission of respectively 172 and 307 kt/year, whereas the best estimate of the emission was 234 kt/year. This is equivalent to a range of plus or minus 30%, or the same range as for other reports on NH_3 emissions.

However, the range of variations for the estimate of NH_3 emissions for other nations with greater differences in regional animal husbandry practices and fewer emission measurements than in the case of the Netherlands is probably larger than 30%.

Table C.26: Netherlands 1990 - Minimum Emissions

	A	B	C	D	E	F	G	H	I
	Category		Calculation factors			Emission factors			
	Animals	Number of animals (x1000)	Inside winter (y)	Inside summer (y)	N excretion ratio summer/ winter	Animal houses winter (kg N/ hd/d)	Animal houses summer (kg N/ hd/d)	Grazing, N loss/N excreted	Spreading N loss/N applied
167	Total cattle	4,830							
168	> 2 y	2,171	0.4000	0.24	1.10	0.0238	0.0450	0.0640	0.256
169	1 y - 2 y	964	0.4000	0.00	1.10	0.0155	0.0292	0.0640	0.256
170	<1 y	1,695	0.6000	0.00	1.10	0.0064	0.0121	0.0640	0.256
172	Total pigs	13,788							
173	Pigs for slaugther	7,746	1.0000			0.0061	0.0061	0.0000	0.256
174	Boars and sows	1,299	1.0000			0.0151	0.0151	0.0000	0.256
176	Total sheep	1,870	0.1000	0.00	1.10	0.0040	0.0086	0.0368	0.256
178	Total goats	77	0.1000	0.00	1.10	0.0040	0.0086	0.0368	0.256
180	Equine	185	0.4000	0.00	1.10	0.0059	0.0126	0.0640	0.256
182	Total poultry	92,765							
183	Laying hens	51,593	1.0000			0.0001	0.0001	0.0000	0.301
184	Table fowl	41,172	1.0000			0.0001	0.0001	0.0000	0.058
186									
	Fertilisers								Emission factor
192	Urea								0.105
193	Ammonium nitrate								0.014
194	Ammonium phosphate								0.035
195	Ammonium sulphate								0.070
196	Other								0.000
198									
201	**Industry**								
202	**Crops**								
203	**Miscellaneous**								
205									

Table C.26: Netherlands 1990 - Minimum Emissions (cont.)

J	K	L	M	N	O	P	Q	R	S	T
N Excretion					NH_3-emissions					
Total (kg N/ hd/y)	Within animal house (kg N/ hd/y)	Outside animal house (kg N/ hd/y)	Total (kt N)	Total in slurry (kt N)	Animal houses (kt N)	Surface spreading (kt N)	Grazing (kt N)	Total (kt N)	% of N excreted	% per category
										47.5
120.600	75.55	45.05	262	148	16.1	37.9	6.3	60.3	23.0	
69.600	26.26	43.34	67	23	2.2	5.9	2.7	10.8	16.1	
28.800	16.62	12.18	49	26	2.4	6.6	1.3	10.3	21.1	
										30.7
12.240	12.24	0.00	95	78	17.3	19.9		37.2	39.2	
30.240	30.24	0.00	39	32	7.2	8.2		15.4	39.2	
27.200	2.50	24.70	51	4	0.3	1.1	1.7	3.2	6.2	1.8
27.200	2.50	24.70	2	0	0.0	0.0	0.1	0.1	6.2	0.1
40.000	15.09	24.91	7	3	0.2	0.7	0.3	1.1	15.4	0.7
										8.3
0.651	0.651	0.00	34	31	2.5	9.4		11.9	35.3	
0.387	0.387	0.00	16	14	1.6	0.8		2.4	15.1	
		Subtotal	**622**	**359**	**50**	**91**	**12**	**153**	**25**	**89.0**
			Fertiliser use (kt N)				NH_3-N losses (kt N)			
				2.0				0.2		
				415.4				5.8		
				4.8				0.2		
				0.2				0.0		
				73.2				0.0		
			Subtotal	**495.6**				**6.2**	**1.3**	**3.6**
								3.3		1.9
								1.5		0.9
								7.9		4.6
							Total	**171.5**		**100.0**

Table C.27: Netherlands 1990 - Maximum Emission

	A	B	C	D	E	F	G	H	I
	Category		Calculation factors			Emission factors			
	Animals	Number of animals (x1000)	Inside winter (y)	Inside summer (y)	N excretion ratio summer/ winter	Animal houses winter (kg N/ hd/d)	Animal houses summer (kg N/ hd/d)	Grazing, N-loss/N excreted	Spreading N loss/N applied
167	Total cattle	4,830							
168	> 2 y	2,171	0.6000	0.1600	1.4000	0.0291	0.0675	0.0960	0.3135
169	1 y - 2 y	964	0.6000	0.0000	1.4000	0.0189	0.0438	0.0960	0.3135
170	<1 y	1,695	0.9000	0.0000	1.4000	0.0078	0.0181	0.0960	0.3135
172	Total pigs	13,788							
173	Pigs for slaugther	7,746	1.0000			0.0075	0.0075		0.3135
174	Boars and sows	1,299	1.0000			0.0185	0.0185		0.3135
176	Total sheep	1,870	0.3000	0.0000	1.4000	0.0094	0.0200	0.0552	0.3135
178	Total goats	77	0.3000	0.0000	1.4000	0.0094	0.0200	0.0552	0.3135
180	Equine	185	0.6000	0.0000	1.4000	0.0138	0.0294	0.0960	0.3135
182	Total poultry	92,765							
183	Laying hens	51,593	1.0000			0.0002	0.0002		0.4512
184	Table fowl	41,172	1.0000			0.0002	0.0002		0.0864
186									
	Fertilisers								Emission factor
192	Urea								0.195
193	Ammonium nitrate								0.026
194	Ammonium phosphate								0.065
195	Ammonium sulphate								0.130
196	Other								0.000
198									
201	**Industry**								
202	**Crops**								
203	**Miscellaneous**								
205									

Table C.27: Netherlands 1990 - Maximum Emission (cont.)

J	K	L	M	N	O	P	Q	R	S	T
N Excretion					NH_3-emissions					
Total (kg N/ hd/y)	Within animal house (kg N/ hd/y)	Outside animal house (kg N/ hd/y)	Total (kt N)	Total in slurry (kt N)	Animal houses (kt N)	Surface spreading (kt N)	Grazing (kt N)	Total (kt N)	% of N excreted	% per category
										46.6
147.4000	104.70	42.70	320	205	22.4	64.2	8.9	95.5	29.9	
104.4000	54.00	50.40	101	48	4.0	15.1	4.7	23.7	23.6	
43.2000	37.38	5.82	73	59	4.4	18.5	0.9	23.8	32.5	
										23.4
14.9600	14.96	0.00	116	95	21.1	29.7		50.8	43.9	
36.9600	36.96	0.00	48	39	8.8	12.3		21.1	43.9	
40.8000	9.56	31.24	76	16	2.0	5.0	3.2	10.2	13.4	3.3
40.8000	9.56	31.24	3	1	0.1	0.2	0.1	0.4	13.4	0.1
60.0000	31.03	28.97	11	5	0.6	1.6	0.5	2.7	24.4	0.9
										9.0
0.8809	0.881	0.00	45	41	4.7	18.4		23.1	50.7	
0.5233	0.523	0.00	22	19	2.9	1.6		4.5	21.1	
		Subtotal	**815**	**527**	**71**	**167**	**18**	**256**	**31**	**83.4**
				Fertiliser use (kt N)				NH_3-N losses (kt N)		
				2.0				0.4		
				415.4				10.8		
				4.8				0.3		
				0.2				0.0		
				73.2				0.0		
			Subtotal	**495.6**				11.5	2.3	3.8
								4.0		1.3
								4.5		1.5
								30.9		10.1
							Total	**306.9**		**100.0**

Table C.28: Netherlands 1990 - The 'Guessed' Errors in the Used Emission and Calculation Factors

	A	B	C	D	E	F	G	H	I	J
	Category		Calculation factors			Emission factors				N Excretion
	Animals	Number of animals (x1000)	Inside winter (y)	Inside summer (y)	N excretion ratio summer/ winter	Animal houses winter (kg N/ hd/d)	Animal houses summer (kg N/ hd/d)	Grazing, N loss/N excreted	Spreading N loss/N applied	Total (kg N/hd/y)
167	Total cattle	4,830								
168	> 2 y	2,171	0.2000	-0.20	0.12	0.1000	0.2000	0.2000	0.100	0.100
169	1 y - 2 y	964	0.2000	0.00	0.12	0.1000	0.2000	0.2000	0.100	0.200
170	<1 y	1,695	0.2000	0.00	0.12	0.1000	0.2000	0.2000	0.100	0.200
172	Total pigs	13,788								
173	Pigs for slaugther	7,746				0.1000	0.1000		0.100	0.100
174	Boars and sows	1,299				0.1000	0.1000		0.100	0.100
176	Total sheep	1,870	0.5000	0.00	0.12	0.4000	0.4000	0.2000	0.100	0.200
178	Total goats	77	0.5000	0.00	0.12	0.4000	0.4000	0.2000	0.100	0.200
180	Equine	185	0.2000	0.00	0.12	0.4000	0.4000	0.2000	0.100	0.200
182	Total poultry	92,765								
183	Laying hens	51,593				0.3000	0.3000		0.200	0.150
184	Table fowl	41,172				0.3000	0.3000		0.200	0.150
	Fertilisers									Emission factor
192	Urea									0.300
193	Ammonium nitrate									0.300
194	Ammonium phosphate									0.300
195	Ammonium sulphate									0.300
196	Other									0.300
	Industry									0.100
202	**Crops**									0.500
203	**Miscellaneous**									0.400

APPENDIX D. ABBREVIATIONS

BML	Bundesministerium für Ernährung, Landwirtschaft und Forsten, Germany
CBS	Centraal Bureau voor de Statistiek [Statistics Netherlands]
CEC	Carbon Exchange Capacity
CIEC	International Scientific Centre of Fertilizers, Belgrade/Göttingen/Vienna
DLO	Directie Landbouwkundig Onderzoek [Diretorate of Agricultural Research, Netherlands]
DLV	Deutscher Landwirschaftsverlag
EEC	European Economic Community
EFMA	European Fertilizer Manufacturers Association, Brussels
EFTA	European Free Trade Association (Austria, Finland, Iceland, Norway, Sweden and Switzerland)
EMEP	Co-operative Programme for Monitoring and Evaluation of the long-range transmission of air pollutants in Europe
FAO	Food and Agriculture Organization of the United Nations
GDR	Former German Democratic Republic, i.e. eastern part of Germany
IFA	International Fertilizer Industry Association, Paris
IFDC	International Fertilizer Development Center, USA
IIASA	International Institute for Applied Systems Analysis, Laxenburg, Austria
IMAG	Instituut voor Mechanisatie Arbeid en Gebouwen now called Instituut voor Milieu- en Agritechniek. [Institute for Agricultural and Environmental Engineering, the Netherlands]
IMOU	Instituut voor Meteorologie en Oceanografie (Rijksuniversiteit Utrecht) [Institute for Meteorology and Oceanografy, State University Utrecht]
IPCS	International Programme on Chemical Safety (of the UN Environment Programme, International Labour organization and World Health Organization), Geneva
KTBL	Kuratorium für Technik und Bauwesen in der Landeswirtschaft, Darmstadt
LEI	Landbouw Economisch Instituut [Agricultural Economics Research Institute], Den Haag
MAFF	Ministry of Agriculture, Fisheries and Food, UK
MLV	Ministerie van Landbouw en Visserij [Department of Agriculture and Fisheries, the Netherlands] now called Ministerie van Landbouw Natuurbeheer en Visserij
MSC-W	Meteorological Synthesizing Centre - West, Oslo
TFI	The Fertilizer Institute, Washington DC
US-EPA	Environmental Protection Agency, USA
USSR	Former Union of Soviet Socialist Republics
VDI	Verein Deutscher Ingenieure [Association of German Engineers]
VDLUFA	Verband deutscher landswirtschaftlicher Untersuchungs- und Forschungsanstalten
VROM	Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer [Department of Public Housing Physical planning and the Environment, the Netherlands]
WHO	World Health Organization (UN)
WMO	World Meteorological Organization (UN)

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