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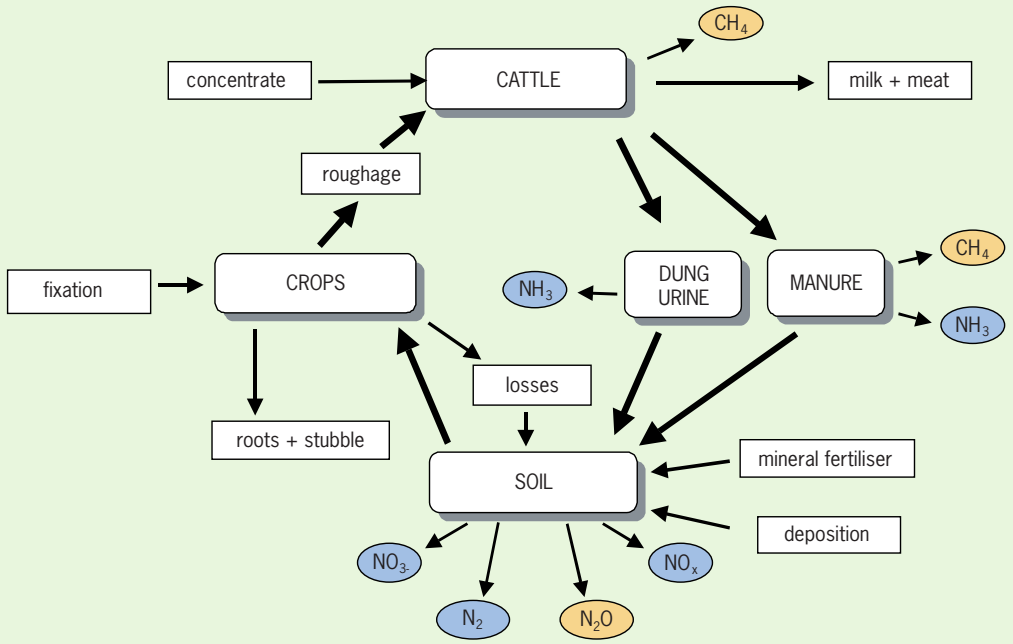
Agricultural land use and emissions of CH_4 and N_2O in Europe

W.J. Corré



Report 40

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Preface

This report is published in the context of the NRP2 project: Interactions between land use, atmospheric concentration of greenhouse gasses and climate in Western Europe and their consequences for post-Kyoto policy options.

The NRP2 project aims to investigate the role of land use and land use change in the climate system and to quantify the consequences of, and a potential for, land use options in relation to 'post-Kyoto' emission reductions and climate policies in North Western Europe. We propose to use, and where needed, to adapt existing state-of-the-art modeling tools in combination with socio-economic analyses, supported by available pan-European data to achieve this aim. We will use plot- and landscape scale, biogeochemical, carbon and vegetation growth models, a regional atmospheric modeling system, a global climate model, and an integrated assessment model.

Summary

A review of the emissions of methane (CH_4) from agriculture and the effects of agricultural land use on the emissions of nitrous oxide (N_2O) in Europe is presented in this report.

Emissions of CH_4 occur during enteric fermentation and during anaerobic storage of manure. Hence, the emission depends largely on animal numbers and not principally on land use, although cattle husbandry, responsible for the major part of the agricultural emission of CH_4 in Europe, is closely related to grassland. The emission from enteric fermentation depends largely on animal species (ruminants vs. non-ruminants, body weight) and is affected by feed quality and production level, but not to a large extent. The emission from manure storage depends on the animal species and is affected by type of storage and by storage temperature. The uncertainties in the emissions from manure storage are very large. Agricultural soils are a negligible source of CH_4. Enteric fermentation is estimated to cause circa 80% of the total emission from agriculture; storage of manure circa 20%.

The total emission of CH_4 from agriculture in 'West Europe' (EU countries plus Norway) was estimated at circa 8650 kton in 1994 and shows a slightly decreasing trend with time. This decrease is caused by a slow decrease in animal numbers. This estimated emission originates for circa 80% from cattle, 10% from sheep and goats, 8% from pigs, 1% from poultry and less than 1% from horses.

Emissions of N_2O occur from the soil processes nitrification and denitrification and depend largely on the amounts and types of N inputs. Emission is affected by soil and weather conditions and by farm management, but the effects are scarcely quantified. The only clear difference concerning soil types is the higher emission from peat soils than from mineral soils; within mineral soils the available data do not show any systematic trend of different emissions from certain soil types. Rainfall has an effect on the emission of N_2O, but this effect is only quantified for short-term effects. Hence, it is not possible to establish regional differences on this basis. Agricultural land use has a distinct effect on emission: grassland shows clearly higher emissions (as percentage of N input) than arable land on the same site. Differences between arable crops seem to be small, except probably for a higher emission rate from potato fields than from other fields and for higher emission rates in no-tillage systems than in conventional tillage systems.

1. Introduction

The enhanced production of greenhouse gases by human activities is supposed to contribute to global warming in the near future. At the Climate Conference in Kyoto in 1997, the international community agreed to reduce the emission of greenhouse gasses. Since that agreement, all possible ways of reducing sources of greenhouse gases are being investigated.

One of the major activities contributing to greenhouse gas emissions is agriculture. Agriculture is an important source of emissions of methane and nitrous oxide, worldwide circa 30% of the methane and 40% of the nitrous oxide is supposed to be directly emitted by agricultural activities.

One of the causes of the enhanced greenhouse gas emissions from agriculture has been land use change from forest and extensively managed vegetations to intensively managed vegetations and field crops. Hence, land use change towards less emitting types of use could contribute to reducing greenhouse gas emissions. Before the effects of land use change can be estimated reliably, the emissions of different types of land use under different soil and climatic conditions must be known.

This report shows a review of the emissions of methane (CH_4) from agriculture and the effects of agricultural land use on the emissions of nitrous oxide (N_2O) in Europe.

Emission of CH_4 can occur from all anaerobic systems where digestible organic matter is present. In agriculture these conditions are met in two systems: the enteric fermentation track of animals and the storage of animal wastes. Agricultural soils are a minor source of CH_4. Hence, the emission of CH_4 from agriculture is not related to land use, but to animal densities. Emission factors for CH_4 are principally not emission factors per hectare, but per head. For an estimation of the effect of changing land use on the emission of CH_4, the changing land use must be evaluated for its effect on the number of animals of different species. Changing land use has an effect on CH_4 emission when it concerns wetlands; this soil type is not part of this review, however.

The emission of N_2O from agriculture originates mainly from the soil processes nitrification and denitrification, and is therefore closely related to land use. The emission depends largely on nitrogen inputs, but is affected by nitrogen removal in products and by soil and climatic conditions. A review was made of the expected effects on the N_2O emission from different soil types, different crops and different regions.

2. Emissions of methane

2.1 Enteric fermentation

2.1.1 Definition

Methane (CH_4) is produced as part of the normal fermentative digestive processes of animals.Within the large fore-stomach, the rumen, of ruminant animals microbial fermentation breaks down complex plant carbohydrates into soluble products. This microbial fermentation enables ruminants to live on plant materials that monogastric animals and humans cannot digest. Methane is produced in the rumen by bacteria as a by-product of the fermentation process. Normally a fraction in the order of 10% of the digestible food is converted and emitted as CH_4.

In monogastric animals microbial fermentation occurs in the large intestine, but the CH_4 produced represents only a very small portion of the digestible feed intake. (Kirchgessner *et al.*, 1995).

2.1.2 Emission calculations

Calculations of the emission of CH_4 from enteric fermentation following IPCC guidelines (OECD, 1991) have been performed by Crutzen *et al.* (1986), Van Amstel *et al.* (1993), & Vermorel (1995).

This calculation is based on three steps:
Step 1: Calculate the percentage of the feed intake that is converted to CH_4 by the animal
Step 2: Estimate the total gross feed energy intake of the animal
Step 3: Multiply the conversion percentage by the total gross feed intake per animal

Step 1 is based on the formula of Blaxter & Clapperton (1965)

$$Ym\ (MJ\ CH_4/100\ MJ\ feed) = 1.30 + 0.112DMD + FL(2.37 - 0.05DMD)$$

- Ym = CH_4 yield in MJ per 100 MJ of gross feed intake
- DMD = percentage of feed digestibility
- FL = feeding level, expressed as multiple of the maintenance level; FL ranges from 1 for non growing and non productive animals to 4 for highly productive animals

Step 2 is based on the net energy demand of the animal and the digestibility of the feed. The net energy demand of an animal depends on body weight, activity, growth rate and production. Net energy demand and feed digestibility control gross energy intake (GEi).

Step 3 is a calculation from MJ CH_4 / 100 days (**Ym x GEi**) to kg CH_4 / animal / year.

The resulting emission factors (kg CH_4 emitted per animal per year) for the various species, types and age classes of animals, calculated by Van Amstel *et al.* (1993), Vermorel (1994) and Crutzen *et al.* (1986) are summarized in Table 2.1.1.

Analysis of the calculations by Van Amstel *et al.* (1993) showed that a number of assumptions, concerning factors such as feed intake and productivity of cattle, are not longer up to date. The emission factor for dairy cows was based on an average body weight of 500 kg and an average milk production of 5000 kg per year. These assumption were valid in the early 1980's, but in 1994, the average values were 600 kg for body weight and over 6400 kg per year for milk production (LEI/CBS, 1996).

Table 2.1.1. Summary of methane emission factors (kg animal $^{-1}$ year $^{-1}$ CH_4) from enteric fermentation in Western Europe.

Animal category	The Netherlands[1]	France[2]	W. Germany[3]	This report
Cattle	73	64 57	57	
- calves	49	25		25
- yearlings	63	58		60
- heifers	63	65		65
- dairy cows	102[4]	100-115[5]	95	50+0.01*m.p.[6]
- other cows	102	85		100
- male 1 – 2 years	93			90
- male > 2 years	93			110
- fattening calves	17.5	25		20
Sheep	8		8	8
Goats	8		5	8
Horses	18		18	18
Pigs	1.5		1.5	1.5

1 *Van Amstel* et al. *1993*
2 *Vermorel, 1995*
3 *Crutzen* et al.*, 1986*
4 *body weight 500 kg, milk production 5000 kg.year^{-1}, average in 1980*
5 *body weight 600 kg, milk production 3400 - 6500 kg.year^{-1}*
6 *based on 1, 2, 3, 4 and Kirchgessner* et al.*, 1995 (m.p. = milk production in kg.cow^{-1}.year^{-1})*

On the basis of normative values for body weights, feed intake and feed digestibility (PR, 1988), the emission factors for cattle were recalculated according to the IPCC guidelines (Van Amstel *et al.*, 1993). On the basis of these findings, mean emission factors for Western Europe were estimated. For dairy cows, however, also measurements of Kirchgessner *et al.* (1995) were used and the emission factor was estimated as a simple function of the milk production level, with different emission factors for different countries as a result. These emission factors, calculated for milk production levels of 1994 and 1998, are summarized in Table 2.1.2.

The emissions of CH_4 from enteric fermentation were calculated as emission per class of animals per year, the total emissions per animal species and per country for 1994 are summarized in Table 2.1.3. For the European Union countries the numbers of the different classes of animals were obtained from Eurostat. For Norway animal numbers were obtained from the FAO statistics at the national level (FAO, 1997). Milk production levels were obtained from FAO statistics for all countries (FAO, 1997).

In a few cases no 1994 figures were available, here the 1993 figures were used. For Sweden only numbers of total cattle and dairy cows were available, the apportioning to the other classes was made by a division to the same proportions as found for countries with the same ratio between total cattle and dairy cows. No data were available in Eurostat for sheep in Denmark and for goats in Denmark, Germany, Ireland and Sweden; these data were taken from FAO statistical data (FAO, 1997).

Table 2.1.2. Milk production levels (kg cow $^{-1}$ year $^{-1}$; FAO, 1997; 1999) and derived CH_4 emission factors from enteric fermentation of dairy cows in 16 European countries in 1994 and 1998 (kg.cow $^{-1}$ year $^{-1}$ CH_4).

Country	milk production level		Methane emission factor	
	1994	1998	1994	1998
Belgium	4800	5400	98	104
Denmark	6200	6700	112	117
Germany	5300	5700	103	107
Greece	3500	4100	85	91
Spain	4400	4600	94	96
France	5400	5600	104	106
Ireland	3600	4400	86	94
Italy	4900	5200	99	102
Luxembourg	4800	5400	98	104
The Netherlands	6400	6900	114	119
Austria	4100	4600	91	96
Portugal	4100	4800	91	98
Finland	6000	6200	110	112
Sweden	6700	7400	117	124
United Kingdom	5500	5700	105	107
Norway	5500	6000	105	110

Table 2.1.3. Summary of yearly CH_4 emissions from enteric fermentation of different animal species in Western Europe in 1994 (kt year $^{-1}$ CH_4).

Country	Cattle	Sheep/Goats	Horses	Pigs	Total
Belgium	211	1	0.4	11	223
Denmark	144	0.8	0.7	17	163
Germany	1082	19	11	38	1150
Greece	40	127	4	2	173
Spain	366	215	11	28	620
France	1496	91	6	23	1616
Ireland	444	48	1	2	495
Italy	497	97	7	12	613
Luxembourg	14	0.1	0.1	1	14
The Netherlands	328	14	2	22	366
Austria	154	3	1	6	164
Portugal	88	33	3	4	128
Finland	82	0.7	0.4	3	86
Sweden	116	4	2	3	24
United Kingdom	811	237	3	12	1063
Norway	64	20	0.4	1	86
Total	5937	911	52	183	7083

2.1.3 Temporal variations

Small variations are to be expected between different years, according to small differences in numbers of animals. During the last 20 years, the emissions gradually decreased because of a decreasing number of cattle, induced by EU milk production restrictions and a steadily increasing milk production level per cow.

For The Netherlands, a decrease from 401 to 365 kt yr^{-1} between 1990 and 1996 was calculated by Spakman *et al.* (1996), using the emission factors of Van Amstel *et al.* (1993).

The revised emission factors from Table 2.1.1 lead to a slightly lower estimate of the total emission (375.7 vs. 381.2 kton in 1994) and to a slightly lower estimate of the decrease of the emission in time. This is caused by a partial compensation of the gradual decrease in number of dairy cows by a gradual increase in body weight and milk production level. According to Kirchgessner *et al.* (1995) this compensation would be circa 40%. This means that the decrease in total CH_4 production from 1990 to 1996 might be only 22 kton instead of the 36 kton calculated by Spakman *et al.* (1996).

Variations in climatic conditions may affect the amount and digestibility of produced roughage. This may cause small variations in overall digestibility of the diet of cattle in different years and in different seasons.

Seasonal variations in numbers of animals and in growth rate or productivity are supposed to be small. For animals grazing in summer, a seasonal difference in methane emission might be expected because of differences in activity and in feed digestibility. The energy demand at maintenance level is supposed to be 17% higher during grazing than during stable feeding, but the energy demand at maintenance level is only a quarter of the energy demand of a high-productive lactating cow (Blaxter & Clapperton, 1965). On the other hand, fresh grass has a better digestibility than conserved feed and as a result hardly any seasonal difference is to be expected.

Diurnal variations in CH_4 emission from enteric fermentation are inherent to ruminant behavior. Periods of grazing or stable feeding are alternated with periods of ruminating. This could cause important temporal variations. Normally grazing activity is high in the early evening, and a larger emission is to be expected during the evening and early night. Stable feeding activity is depending on farm management practices and is therefore less predictable. Measurements of these variations have not yet been performed.

2.1.4 Uncertainties

At The Netherland's national level, emission factors are supposed to have an uncertainty range of 15% (Van Amstel *et al.*, 1993). At the European level the uncertainty range should probably be extended. Combined with uncertainties in animal numbers and seasonal differences, an uncertainty range of 30% for the total emission on a daily basis seems to be reasonable.

During the year, small variations in animal numbers, productivity, feed digestibility and activity occur. The variations are assumed to add an additional 5 to 10% of variability, with an uncertainty range of 35 to 40% for the emission on a daily basis as a result.

An uncertainty range of the emission factors of 15% is reasonable, provided that the assumptions of factors such as feed intake are the best possible estimates. When these basic factors change, recalculation of the emission factors is needed to prevent extension of the uncertainty range. For example, the emission factor for dairy cows was increased by 12% between 1980 and 1994 (Tables 2.1.1 and 2.2.2). A regular critical update of the emission factors is necessary to prevent extension of

the uncertainty range. Such an update is also very important for an accurate estimate of the effects of future changes in animal numbers and animal productivity, as induced by national and European Union policies.

2.2 Animal wastes

2.2.1 Definition

In animal wastes CH_4 is produced by bacteria under anaerobic conditions. These conditions are met during storage. When animal waste is directly returned to the soil during grazing, no methane will be produced (Flessa *et al.*, 1996; Jarvis *et al.*, 1995).

Animal manure can be stored as slurry (i.e. a mixture of dung and urine) or as solid manure (mostly a mixture of dung and litter). Slurries are completely anaerobic, stored solid manure is partly anaerobic, due to large oxygen consumption by composting processes.

The amount of CH_4 produced depends on the content of digestible compounds, the quality of these compounds (i.e. the potential amount of CH_4 that could be produced), storage duration and temperature.

2.2.2 Emission calculations

Measurements of CH_4 emissions from stored manure are scarce and extremely variable (a.o. Husted, 1994) and thus estimates have a very large uncertainty. National estimates are only published for the Netherlands, Denmark and Sweden. For The Netherlands calculations of the emission of CH_4 from animal wastes following IPCC guidelines (OECD, 1991) have been performed by Van Amstel *et al.* (1993).

The IPCC recommends the method of Casada & Safley (1990), consisting of five steps:

Step 1: define different waste categories and waste handling systems
Step 2: estimate the degradable material content (volatile solids, VS) in each waste category
Step 3: estimate the potential CH_4 emission per unit of degradable material in each waste category (Bo)
Step 4: estimate the fraction of the potential emission that is actually emitted for each waste handling system (Methane Conversion Factor, MCF)
Step 5: estimate the actual CH_4 emissions by multiplying the actual emission rate by the volatile solids content in each category

This calculation results in emission factors (kg CH_4 emitted per ton of manure produced) for the various species, types and age classes of animals.

Recently, Van der Hoek *et al.* (in: Spakman *et al.*, 1996) reviewed the literature on CH_4 emissions from animal manure. Their values for the emission factors of animal manure were taken from Van Amstel *et al.* (1993), with one exception. Van Amstel *et al.* (1993) calculated different figures for cattle and for fattening calves. This difference was partly based on a difference in composition, and partly on a difference in storage duration. The difference in manure composition is a result of a difference in diet composition: fattening calves do not eat roughage to avoid coloring of the meat. Van der Hoek *et al.* (in: Spakman *et al.*, 1996) applied these different emission factors to manure of dairy cattle and manure of beef cattle. The latter group does include fattening calves (689,516 in 1994), but also other beef cattle (749,151 in 1994), which have basically the same diet as dairy cattle. Therefore, the emission

factor, introduced for fattening calves and later applied to all beef cattle, is used in this study for fattening calves only.

Van Amstel *et al.* (1993) assumed that cattle manure is stored anaerobically for less than one month and manure of fattening calves for more than one month. However, the average duration of storage of cattle manure is at least three months, because spreading is prohibited in the winter period in The Netherlands. This is why in this study the emission factor for cattle manure was recalculated. This recalculation was based on a different estimation of the 'Methane Conversion Factor' (MCF). Van Amstel *et al.* (1993) estimated the MCF at 10% for liquid manure stored for more than one month, and at 5% for liquid manure, stored for less than one month and for solid manure. For cattle manure 5% was estimated by Van Amstel *et al.* (1993), but based on a storage duration of three month, and liquid storage of 85 to 90% of the manure, an emission factor of 0.13 seems more reasonable (Corré *et al.*, 1997).

The emission factors, published by van Amstel *et al.* (1993) and by Van der Hoek *et al.* (in: Spakman *et al.*, 1996) and the factors used in this report are summarized in Table 2.2.1.

Table 2.2.1. Summary of emission factors from storage of animal manure (in kg ton^{-1} CH4).

Animal category	Van Amstel *et al.* (1993)	Spakman *et al.* (1996)	This report
Cattle	0.698		1.3
Dairy cattle		0.698	
Beef cattle		2.534	
Fattening calves	2.534		2.5
Sheep and goats	3.009	3.009	3.0
Pigs	2.979	2.979	3.0
Poultry	4.110	4.110	4.1

For the Netherlands, a total emission from manure of 119 kton CH_4 was estimated for 1994, based on the emission factors of Table 2.2.1 (calculated following IPCC guidelines), standard manure production figures of different classes of animals (LEI-DLO, pers. comm.) and the numbers of the different classes of animals (CBS, 1997).

For Denmark a total CH_4 emission from cattle and pig manure of 28 kton was estimated for 1990, based on standard manure productions per animal and measurements of the emission from four individual manure storage systems (Husted, 1994).

For Sweden a total emission of 22 kton was estimated for 1990, as a mean (5.5%) of a low and a high estimate of 1 and 10% of the potential CH_4 production from all manure produced (Svensson *et al.*, 1991).

For most countries no data are published on amounts of stored manure, mean storage duration and type of storage (liquid or dry), nor on estimates of emission factors. Therefore, the estimates for this report were based on the emission factors for The Netherlands, summarized in Table 2.2.1, on the estimates of stored manure production per animal in The Netherlands, obtained from LEI-DLO (pers. comm.), and on the animal numbers described in paragraph 2.1.2.

The emissions were calculated as emission per animal category per country and are summarized in Table 2.2.2.

Table 2.2.2. Summary of yearly methane emissions from storage of animal manure of different animal categories in Western Europe in 1994 (kt year $^{-1}$ CH_4).

Country	Cattle	Fattening calves	Sheep, Goats	Pigs	Poultry	Total
Belgium	33	2	0.0	30	3	68
Denmark	24	0.1	0.0	47	2	73
Germany	177	2	0.0	108	10	297
Greece	6	0.8	0.2	5	3	15
Spain	47	11	0.1	79	13	150
France	220	9	0.1	63	30	322
Ireland	69	0	0.1	7	0.4	75
Italy	77	3	0.1	35	15	130
Luxembourg	2	0.0	0.0	0.3	0.0	3
The Netherlands	45	7	0.0	61	10	123
Austria	25	0.8	0.0	16	1	44
Portugal	13	0.5	0.0	12	3	29
Finland	10	3	0.0	6	0.6	20
Sweden	15	1	0.0	6	1	24
United Kingdom	126	0.1	0.4	34	14	175
Norway	11	0.0	0.0	3	0.4	14
Total	901	40	1	514	106	1562

2.2.3 Temporal variations

Temporal variations are important, and are principally seasonal. Variations are caused by differences in temperature and by differences in stored amounts. Both production and utilization are variable in time. Production of stored manure from cattle (except from fattening calves), sheep and goats is much larger in winter than in summer; production of stored manure from fattening calves, pigs and poultry is almost constant during the year.

Utilization of manure depends on soil type, land use and type of manure, governmental regulations and farming practices. In a number of countries application of manure is prohibited during the winter period, in others it is not. Depending on agricultural practices, application can be concentrated in early spring (common on arable land on sandy soils and grassland), in autumn (common on arable land on clay soils) or in winter (common on grassland).

No data are available for the variations in stored amounts and the effect of seasonal temperature on emission. The emission factors are principally meant for estimation of yearly emissions.

2.2.4 Uncertainties

The uncertainties in emissions from animal wastes are very large, but not quantified (Van Amstel *et al.*, 1993).

Sources of uncertainty are:
- composition of manure (volatile solids content),
- potential emission from volatile solids,
- actual emission fraction (Methane Conversion Factor); mean and seasonal variation,

- production of manure per waste category and per waste handling system; mean and seasonal variation, and
- actual amounts in storage per waste category and per waste handling system; mean and seasonal variation.

The uncertainty ranges of the emissions were never estimated, and measurements are too scarce and variable (Husted, 1994) to give any general idea on the variability of the emissions. An uncertainty range of much more than one hundred percent seems to be possible for the total emission on an annual basis. For Sweden, the estimated range was 4 to 40 kton per year, for example (Svensson *et al.*, 1991). For the emission on a daily basis, even a much larger uncertainty range is to be expected.

2.3 Organic soils

2.3.1 Definition

Organic soils in this report are defined as soils with at least a top layer mainly consisting of organic material, but not classified as wetlands. The soils in Western Europe meeting this definition are predominantly drained organic soils with an agricultural land use.

2.3.2 Calculation of emissions

CH_4 emitting organic soils, not being wetlands, are of minor or no importance in Western Europe. CH_4 emissions from drained organic soils only occur during very wet periods. When this is more than incidental, these soils will still be classified as wetlands.

Recent measurements on farmed drained organic soils in The Netherlands and Sweden have shown that these soils are net CH_4 sinks (Van den Pol-van Dasselaar *et al.*, 1997; Van den Pol-van Dasselaar *et al.*, 1998).

CH_4 emissions from drained organic soils (about 1500 km^2 in the Netherlands), as referred to by authors such as Van Amstel *et al.* (1993), appear to be based on emissions from soils with natural vegetations. In The Netherlands, drained organic soils are used for intensive grassland farming and will be net CH_4 sinks.

2.4 Total CH_4 emissions from agriculture

In the previous chapters, estimates were made of the CH_4 emissions from different agricultural sources. Total emission from the EU countries and Norway was estimated at circa 7100 kt yr^{-1} from enteric fermentation, circa 1550 kt yr^{-1} from storage of manure and 0 kt yr^{-1} from agricultural soils. On average, circa 82% of the total emission originates from enteric fermentation. This fraction is high for ruminants, circa 86% for cattle and nearly 100% for sheep and goats, and low for monogastric animals, circa 26% for pigs and 0% for poultry. For horses, no information on CH_4 emission from manure is available.

Of the total emission circa 80% originates from cattle, 10% from sheep and goats, 8% from pigs, 1% from poultry and less than 1% from horses.

Total emission per country and per class of animals is shown in Table 2.4.1. On the basis of these emissions and the corresponding animal numbers, emission factors were calculated for the total emission per animal per year. For all animal species these factors are the same for all countries, except for cattle. Cattle are the only species for which classes are distinguished with different emission factors, depending on age and production level. These total emission factors are shown in Table 2.4.2. The emission factor for cattle is hardly related to the milk production level of the dairy cows ($r^2 = 0.10$).

This relationship is apparently disturbed by different ratios of young cattle to adult cattle and of dairy cattle to other cattle. Hence, when only figures are available on the total number of cattle, like in FAO statistics, the use of an emission factor of 80 kg head^{-1} year^{-1} CH_4 is recommended.

Table 2.4.1. Summary of yearly CH_4 emissions from agriculture for different animal categories in Western Europe in 1994 (kton year^{-1} CH_4).

Country	Cattle	Sheep, Goats	Pigs	Poultry	Horses	Total
Belgium	246	1	41	3	0.4	292
Denmark	168	0.8	64	2	0.7	235
Germany	1261	19	146	10	11	1447
Greece	47	127	7	3	4	188
Spain	424	215	107	13	11	770
France	1725	91	86	30	6	1938
Ireland	512	48	9	0.4	1	571
Italy	577	97	47	15	7	742
Luxembourg	16	0.1	0.4	0.0	0.1	17
The Netherlands	380	14	83	10	2	489
Austria	180	3	22	1	1	208
Portugal	102	33	16	3	3	157
Finland	95	0.7	8	0.6	0.4	105
Sweden	132	4	8	1	2	147
United Kingdom	937	237	47	14	3	1238
Norway	75	20	4	0.4	0.4	100
Total	6877	912	797	106	52	8644

Table 2.4.2. Emission factors for CH_4 emissions from agriculture of different animal categories in Western Europe in 1994 (kg.head^{-1}year^{-1} CH_4).

Country	Cattle	Sheep, Goats	Pigs	Poultry	Horses
Belgium	77.9	8.0125	5.7	0.102	18
Denmark	79.2	8.0125	5.7	0.102	18
Germany	78.7	8.0125	5.7	0.102	18
Greece	78.6	8.0125	5.7	0.102	18
Spain	80.2	8.0125	5.7	0.102	18
France	83.9	8.0125	5.7	0.102	18
Ireland	83.6	8.0125	5.7	0.102	18
Italy	80.3	8.0125	5.7	0.102	18
Luxembourg	80.3	8.0125	5.7	0.102	18
The Netherlands	79.9	8.0125	5.7	0.102	18
Austria	77.2	8.0125	5.7	0.102	18
Portugal	80.8	8.0125	5.7	0.102	18
Finland	79.4	8.0125	5.7	0.102	18
Sweden	90.5	8.0125	5.7	0.102	18
United Kingdom	83.1	8.0125	5.7	0.102	18
Norway	76.9	8.0125	5.7	0.102	18
Mean	81.4				

3. Emissions of nitrous oxide

3.1 Definition

Nitrous oxide is produced as an intermediate product of the processes nitrification and denitrification in soil and water. Nitrification is the microbial oxidation of ammonium to nitrate; normally an extremely small part (< 1%) of the oxidized nitrogen is emitted as N_2O. Low oxygen status and low pH decrease nitrification rates, but increase the proportion of oxidized N, emitted as N_2O. Denitrification is the microbial anoxic reduction of nitrate to di-nitrogen and under strictly anoxic conditions normally hardly any N_2O is emitted. The proportion of reduced N emitted as N_2O is increased by the presence of oxygen, a high concentration of nitrate and a low pH, and can reach a substantial value (e.g. Firestone & Davidson, 1989).

3.2 Emission calculations

Calculations of the emission of nitrous oxide from agricultural land following IPCC guidelines (OECD, 1991) have been performed by, e.g., Mosier *et al.* (1998, at a global level) & Spakman *et al.* (1994, for The Netherlands).

The principle of the calculation of N_2O emission is the emission factor. An emission factor is estimated for each source of N that can lead to N_2O emission, and the emission is calculated by multiplying this factor with the source strength. Emission factors are estimated for nitrogen inputs as mineral fertilizer, as animal excreta and as biological fixation as direct emissions, and for leached nitrate and volatilized ammonia as indirect emissions. The calculated emission is increased by a standard amount for unfertilized soil. The default IPCC emission factors and the emission factors used in the national inventories of N_2O emissions in The Netherlands are listed in Table 3.1.

Table 3.1. Emission factors for N_2O from agriculture.

Source	IPCC default [1]	The Netherlands[2]		
		mineral soil	organic soil	
Unfertilized soil	5000	1000	10000	g N/ha
Fertilizer N	12.5	10 x 0.98[3]	20 x 0.98[3]	g N/kg N
Manure N:				
- standard application	12.5	10	20	g N/kg N
- low emission appl.	12.5	20	20	g N/kg N
- in stable and storage	1	1	1	g N/klg N
- in pastures	20	14.7	14.7	g N/kg N
Biological fixation	12.5	10	10	g N/kg N
Leached nitrate	25	--		--
Volatilized ammonia	10	--		--

[1] *Mosier et al., 1998*
[2] *Kroeze, 1994*
[3] *10 g per kg after adjustment for ammonia volatilization*

The IPCC default emission factors are global estimates; they should only be used when no information on emission on a national or regional level is available. For the national inventories in The Netherlands, slightly different emission factors are used. In 1994 Kroeze published different emission factors for two soil types, mineral soils and organic soils, and for two manure application methods. With low emission application methods, less ammonia is volatilized and more N will remain in the soil, with a supposedly higher emission of N_2O as a result. These factors were based on very limited research in The Netherlands and in 1997 Velthof published a new set of emission factors for The Netherlands on the basis of local research, at least for the most important emission factors. However, national inventories are still based on the emission factors of Kroeze (1994). The emission factors of Kroeze (1994) and Velthof (1997) are summarized in Table 3.2. Total emissions from agriculture in The Netherlands, calculated with both sets of emission factors, are summarized in Table 3.3.

Table 3.2. Emission factors for N_2O from agriculture in the Netherlands.

Source	Kroeze, 1994		Velthof, 1997		
	mineral soil	organic soil	mineral soil	organic soil	
Unfertillized soil	1000[1]	10000[1]	900[2]	5300[2]	g N/ha
Fertilizer N	10 x 0.98[3]	20 x 0.98[3]	10	30	g N/kg N
Manure N:					
- standard application	10	20	3	4	g N/kg N
- low emission appl.	20	20	6	10	g N/kg N
- in stable and storage	1	1	0.05	0.05	g N/kg N
- in pastures	14.7	14.7	25	60	g N/kg N
Biological fixation	10	10	5	5	g N/kg N
Leached nitrate	--	--	25	25	g N/kg N
Volatilized ammonia	--	--	5	5	g N/kg N

[1] *excluding natural background emission, average 500 g N ha^{-1}*
[2] *including natural background emission*
[3] *10 g kg^{-1} after adjustment for ammonia volatilization*

Table 3.3. Emission of N_2O from agriculture in the Netherlands in 1994 in kton N_2O per year.

Source	Spakman *et al.,* 1996	Velthof, 1997
Unfertillized soil	4.7[1]	4.4[2]
Fertilizer N	6.4	7.1
Manure N:		
- application	10.8	3.8
- in stable and storage	0.7	0.1
- in pastures	3.8	6.1
Biological fixation	0.2	0.1
Leached nitrate	-- \ > (3.8)[3]	4
Volatilized ammonia	-- /	1
Total	26.6 (30.4)	27

[1] *excluding natural background emission, 1 kton*
[2] *including natural background emission*
[3] *indirect N_2O emissions are not calculated as emissions from agriculture*

Total N_2O emissions, calculated with the different sets of emission factors, are not dramatically different. The contribution of the various sources, however, differ substantially. This is an important conclusion, because the effect of changing agricultural practices on the emission substantially depends on the set of emission factors used. A striking example is summer grazing of cattle versus cutting and stable feeding. According to Kroeze (1994) more N_2O will be emitted with stable feeding, but according to Velthof (1997) substantially more N_2O will be emitted with summer grazing.

For agriculture usually only nitrogen inputs are used as emission determinants. However, it is clear that soil and climatic factors do affect emission and that also other agricultural management practices than lowering the input of nitrogen can change N_2O emission (Oenema *et al.*, 1998).

3.3 Effects of soil type

In The Netherlands separate emission factors are used for N inputs on mineral soils and on organic soils in the national inventories of the emission of N_2O (Kroeze, 1994; Velthof, 1997). N inputs on organic soils are generally estimated to cause circa twice as much emission, whereas the background emission, due to mineralisation, is much higher in organic soils. Also in other countries, high N_2O emission rates have been measured from drained peat soils under agricultural use (Ambus, 1998; Augustin *et al.*, 1998; Clough *et al.*, 1998).

In 1990, Eichner concluded on the basis of a literature survey that the available data did not indicate a trend between emissions of N_2O and a particular soil type. Arah *et al.* (1991), however, did find a strong effect of soil type: on one light soil the emission of N_2O was one order of magnitude higher than on three heavier textured soils; a larger N_2 to N_2O ratio from denitrification in the heavier textured soils was suggested as cause. In contrast, Sitaula *et al.* (1997) and Stevens & Laughlin (1998) did find higher N_2O emission rates from clay soils. A monitoring study on a range of mineral soils from sand to clay with arable crops did not show a clear difference related to soil type (Kaiser *et al.*, 1996). N_2O emissions were low at all sites and as far as relations were found between soil properties (clay content and organic matter content) and N_2O emission in this study, these relations were based on the relatively large emission from one site: a permanent grassland, and not on differences between different arable sites. It is concluded that soil texture alone is not likely to cause systematic differences in N_2O emissions.

Another aspect of soil type, which is likely to show effects on the emission of N_2O, is soil wetness. Generally, N_2O emission rates are highest from moderately wet soils, where nitrification takes place and where denitrification can result in a considerable proportion of N_2O in the emitted gasses. Both dry soils and extremely wet soils show less N_2O emission. For agricultural soils it can generally be concluded that wetter soils will have larger N_2O emission rates, although no quantitative studies are known. According to the results of Arah *et al.* (1991), this effect could be stronger for light-textured soils. For peat soils the situation can be different: drained peat soils might show very high N_2O emission rates because of a high mineralisation rate of the organic N in the soil (Velthof, 1997). Extremely wet soils, like undrained peat soils, are not in agricultural use.

3.4 Effects of land use

According to the IPCC recommended calculations, land use is supposed to have only indirect effects on the emission of N_2O via differences in N inputs. On the other hand, there is vast evidence that N_2O emission rates from grassland are generally clearly higher than the emission rates from arable land. Partly, this difference will be due to large inputs of N from grazing animals and interaction with soil type: generally grassland is found on wetter soils. But even in a comparison between arable land and ungrazed permanent grassland at the same site, more than twice as much N_2O was emitted from grassland, in absolute amounts as well as in the fraction of applied fertilizer-N (Kaiser *et al.*, 1996).

This difference will be caused by the larger input of plant organic material in the soil and the absence of soil tillage in grassland. Similar differences between grassland and arable land on the same site were found by MacTaggart *et al.* (1997) and by Smith *et al.* (1998a). In addition, Mummey *et al.* (1998) found that conversion of agricultural land from conventional tillage to a no-till system did increase the emission of N_2O.

Direct comparisons between different arable crops are very few. In a direct comparison of three years Kaiser *et al.* (1998) did not find different emission rates for fields with winter wheat, winter barley, sugar beet or winter rape. Smith *et al.* (1998b) did find a clearly higher N_2O emission from a potato field than from fields with cereal crops. A large proportion of the emission from the potato field occurred after harvest. Potatoes are known for leaving a large residue of mineral N in the soil after harvest; this might contribute to a higher emission. No conclusions on differences in emission rates between fields with different crops can be drawn from indirect comparisons: possible differences will generally be caused by differences in soil, climate, weather and agricultural practices.

Significant changes in N_2O emission are to be expected with changes in land use from agricultural land to non-agricultural land. The emissions from N inputs will stop and the emission level will be reduced to the level of unfertilized agricultural soil. After a number of years the emission will be further reduced towards the natural background level.

3.5 Effects of regions

Differences in climate or differences in agricultural practices could cause regional differences in N_2O emission. Especially the nitrogen input level could show regional differences. The effect of temperature seems to be too small to result in regional differences in Europe. Rainfall will interfere with soil wetness and will have an effect on emission, but only short-term quantifications of this effect are known.

Mineral fertilizer use for arable crops is not very different between regions; it is mostly reasonably adapted to expected yields. For grass, regional differences exist, in some regions grassland management is much more intensive than in others. For manure N also differences exist: some regions in The Netherlands, Belgium, France, Germany, Denmark and the United Kingdom have very high animal densities, resulting in large N inputs in manure on both grassland and arable crops.

N input levels could be obtained from statistical data: N fertilizer use and manure production (from animal numbers), based on quantities per hectare agricultural land.

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