Methane and nitrous oxide emissions from UK agricultural livestock.

Inventaire des émissions de méthane et de protoxyde d'azote issues des activités d'élevage en Grande-Bretagne.

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Abstract

UK inventories for nitrous oxide (N_2O) and methane (CH_4) were constructed for farmed livestock in order to quantify emissions and provide information on areas where abatement practices may be potentially useful. The inventories were constructed separately using Excel spreadsheets conveniently divided into the different categories of animal, viz. cattle, pigs, sheep, poultry and deer. Emissions from grazing land and land used for conserved grass or tillage crops were included for completeness. N_2O and CH_4 emissions from each of the animal categories were further divided into a) emissions from buildings, b) manure stores and c) following application of manures to the land. Where possible we made our own measurements, i.e. under UK conditions but took literature values where there was little or no other data available. Our inventory estimates were 21.1 kt N_2O per year and 845.0 kt CH_4 per year. Because of the approach we estimate the error associated with the total N_2O emissions to be ± 50%. The emission factors we used are discussed in this paper, as are potential abatement practices.

Résumé

L'augmentation de la concentration atmosphérique globale du protoxyde d'azote (N_2O) au cours de la dernière décennie est due à l'utilisation plus intensive des engrais chimiques et engrais de ferme, tandis que celle de méthane (CH_4) (produit dans les processus de méthanogénèse) est le résultat de l'augmentation du nombre d'animaux ruminants et de la culture de riz. Ces pertes gazeuses se produisent à chaque étape dans le cycle de production, par exemple, dans les bâtiments pendant le stockage et suivant l'application du fumier aux champs. Cet article décrit les pertes relatives de N_2O et CH_4 de chacun de ces compartiments.

Les émissions de N_2O et CH_4 ont été mesurées dans les bâtiments de ventilation forcée et naturelle. Les pertes pendant le stockage du fumier ont été mesurées en

utilisant des méthodes de « tunnel » et des méthodes micro-météorologiques, alors que les émissions suivant l'épandage sur le sol ont été mesurées en utilisant une combinaison de méthodes de cloche ou boîte à couvert statique et active.

La production totale de CH_4 en 1995 était de l'ordre de 846 kt, dont 75% venait de la fermentation entérique des vaches. Pour la même période, le total des émissions de N_2O était de 18,3 kt, dont le stockage (5,7 kt) et l'application des engrais chimiques aux champs (5,4 kt) sont les sources principales.

A cause de la grande influence de la fermentation entérique et des engrais chimiques sur les inventaires de CH_4 et de N_2O, respectivement, il existe des incertitudes considérables dans ces estimations. Cependant, ces inventaires suggèrent qu'afin de diminuer les pertes de CH_4 une manipulation de l'alimentation des animaux peut être nécessaire, alors que les émissions de N_2O peuvent être diminuées par une utilisation plus efficace des engrais chimiques.

1. Introduction

Methane is the second most important greenhouse gas after CO_2, contributing approximately 20% to global warming (Bouwman, 1990), and is produced primarily by microbial degradation of organic material under anaerobic conditions, e.g. in the rumen during enteric fermentation. Manures contain biodegradable C, often in an anaerobic conditions, thus favouring methanogenesis and the emission of CH_4. Methane emissions have been reported from manure stores (Husted, 1993) and following slurry applications to land (Chadwick *et al*., 1997). Until recently, CH_4 emissions from livestock waste have been largely neglected, although CH_4 budgets given by Safely *et al.* (1992) revealed that such wastes may contribute to up to 10% of the total anthropogenic emission of CH_4. In the UK the estimated annual production of solid manures and slurries is 85 million tonnes (Pain *et al*, 1998), therefore the livestock sector represents a large potential source of N_2O and CH_4.

Nitrous oxide is a potent greenhouse gas and is also implicated in depletion of stratospheric ozone (Cicerone, 1987). Agriculture is partially responsible for the rise in atmospheric concentration of N_2O, 0.2-0.3% per annum, observed in recent years (Bouwman, 1990). N_2O is the product of both nitrification (Bremner and Blackmer, 1978) and denitrification (Firestone and Davidson, 1989) and is produced at any stage of livestock production when conditions become favourable. e.g. manure applications to land return biodegradable carbon (C), a nitrifiable nitrogen (N) source (principally ammonium) and moisture to the soil, thus favouring nitrification and denitrification. Nitrous oxide emissions have been shown to increase following application of manures to agricultural soils (Paul *et al*., 1993; Sommer *et al*. 1996 and Chadwick, 1997). There is less information on emissions of N_2O from other stages of livestock production, *viz.* animal houses and manure stores.

This paper describes 2 UK emission inventories, for N_2O and CH_4 from farmed livestock, which have been constructed in a transparent form on spread-sheets which can be easily updated as new information becomes available. They have been compiled using, as far as possible, direct experimental data gathered under UK conditions. Literature values for emission factors have also been used to corroborate our measurements and also provide missing emission factors where appropriate. We also identify potential abatement practices.

2. Materials and methods

Inventory construction

The inventories were constructed on computer spreadsheets (EXCEL 5.0) and conveniently partitioned into emissions from each livestock group in the UK, i.e. cattle, pigs, poultry, sheep and deer. For completeness, emissions from conserved grassland and tillage crops were included, as they provide feedstuffs for livestock enterprises. Each livestock group was further divided into emissions from animal houses, manure stores and following land spreading of manures. Animal numbers from the June 1996 census were used (HMSO, 1997), the only exceptions were poultry and farmed deer. The census data for 1996 were not available for these classes of animals therefore 1993 numbers (HMSO, 1994) were used for poultry and 1995 numbers for deer (HMSO, 1996).

Emission factors

The construction of the inventories required the input of emission factors (EFs) for N_2O and CH_4. For housing, the EF were expressed as g N_2O or CH_4 lu^{-1} d^{-1}, where lu = livestock unit or 500 kg liveweight. Losses from manure stores were expressed as g N_2O or CH_4 m^{-3} slurry or t^{-1} FYM. Emission factors for land spreading were in g N_2O or CH_4 m^{-3} slurry or t^{-1} FYM.

Determination of emission factors from animal houses

Long-term emissions (several weeks) of N_2O and CH_4 were quantified from a fattening piggery (300 pigs) and a dairy cow house (100 cows), using automated gas chromatography (GC) (Sneath *et al*., 1997). Also, continuous measurements over a 24 hour period were made from a large number of different types of pig, poultry and cattle buildings, under both summer and winter conditions using infra-red analyses (Sneath, 1996).

Determination of emissions from manure stores

Since N_2O production from slurries requires nitrate to be present and slurries are extremely anaerobic, we set N_2O emissions from slurry stores and dirty water tanks at zero. However, for solid manure stores there is limited air access to the manure providing a mixture of anaerobic and aerobic zones (Kirchmann, 1985). Therefore conditions exist for both nitrification and denitrification within FYM heaps, increasing the opportunity for N_2O production. Methane production and emission is possible from both slurries and solid manures.

In this study we have used N_2O and CH_4 EFs we measured from beef FYM and one for N_2O from pig FYM by Sibbsen and Lind (1993). No UK data were available for poultry manure, therefore we used the EFs calculated for a poultry building we monitored, assuming that the N_2O and CH_4 were generated by the excreta and not the birds themselves. Emission rates were multiplied by the volume of manure stores, which was estimated by Nicholson and Brewer (1997).

Determination of land spreading emission factors

Nitrous oxide and CH_4 EFs were measured from grassland following applications of different manures at several times of the year. Typical application rates were used and emissions measured using both static and active cover boxes (Mosier, 1989). Emissions were monitored until rates of N_2O emission had decreased to background levels (untreated controls), usually between 3 and 4 weeks. Average EFs were calculated for each manure type and multiplied by the volume of each manure type applied to agricultural soils each year. We assumed that EFs for grassland and arable land were the same.

Emission factors for conserved grassland and tillage land

Nitrous oxide emissions from these areas of land were estimated by multiplying the mass of ammonium nitrate, urea and 'other' N fertilisers applied each year (Burnhill *et al*., 1994 and DANI, 1994) by the average %N loss as N_2O of N applied, as suggested in the IPCC guidelines for National Greenhouse Gas Inventories (IPCC 1997). However, we used the average fractional loss values as reviewed by Eichner (1990). These emission factors were 0.44%, 0.11% and 0.16%, for ammonium nitrate, urea and 'other' fertilisers, respectively. Methane emissions from this land were set at zero, although we recognise that some CH_4 oxidation may occur.

Emission factors for grazing

A grazing term was included in the cattle, pig and sheep sections of the inventory. Non-milking dairy cattle were presumed to graze for 183 days, as were beef cattle, bulls and other cattle older than one year. Calves < 6 months old and 6-12 months old graze for 90 and 150 days, respectively. The grazing time for milking cows was reduced by 12.5% to 160 d to account for time spent in the buildings during milking and in moving between pasture and the milking parlour during the grazing season. Losses of N_2O from grazing cattle were divided into losses resulting from fertiliser applied and losses from direct excretal returns to pasture. The former term was calculated from the area of land receiving N fertilisers as categorised in the Survey of Fertiliser Practice for Great Britain (Burnhill, 1994) and the %N loss as N_2O of N applied as reviewed by Eichner (1990). This term is included in the losses of N_2O from conserved grassland.

The annual N_2O emission from excretal returns from grazing cattle, 3.1 kt, was taken from the long-term experimental data of Yalmulki *et al*. (1998) who monitored emissions from dung and urine patches. Since no direct data were available for outdoor pigs and sheep, emissions of N_2O from excretal returns were estimated by using the emission factor based on pig slurry and cattle FYM applied to grassland, respectively.

Losses of CH_4 were divided into losses from enteric fermentation within the gut of ruminants and CH_4 emissions from excretal returns. The EF for enteric fermentation was the same as that used for enteric fermentation within animal houses. However, CH_4 emissions from excretal returns were estimated from slurry and FYM applications to land, corrected for excretal rates.

3. Results

Housing

Table 1 illustrates the N_2O and CH_4 emissions from housed animals. The largest N_2O emissions result from cattle and poultry. As expected the largest methane emission is from cattle and is almost entirely the product of enteric fermentation. Our measured EF for enteric fermentation from dairy cattle, 270 g lu^{-1} d^{-1}, is somewhat higher than the 190 g lu^{-1} d^{-1} reported by Blaxter and Clapperton (1965) who measured CH_4 emissions from individual cattle in metabolic crates, but similar to the 260 g lu^{-1} d^{-1} reported by Kinsman *et al* (1995).

Animal category	Management system	CH_4 emission (kt)	% CH_4 loss from housing	N_2O emission (kt)	% N_2O loss from housing
Cattle	Dairy				
	Slurry based	148.2	40.0	0.46	9.2
	Straw based	34.9	9.4	0.11	2.2
	Beef	114.0	30.8	1.05	21.0
	Calves (dairy and beef)	46.0	12.4	0.17	3.4
Sheep	Straw based	4.6	1.2	<0.01	0.0
Pigs	Straw based	4.3	1.2	0.07	1.4
	Slurry based	17.2	4.6	0.07	1.4
Poultry	Broiler sawdust based	0.4	0.1	1.46	29.4
	Layer no bedding	0.9	0.2	0.50	10.0

	Pullets Others	0.1 0.4	<0.1 0.1	0.09 0.99	1.8 19.8
Deer	Straw based	0.1	<0.1	0.02	0.4
Total		371.1	100.0	4.99	100.0

Table 1.
CH_4 and N_2O emissions from animal houses in the UK.

Storage

The storage losses of CH_4 and N_2O are shown in Table 2. The greatest emissions of nitrous N_2O were from the beef cattle manure and poultry manure heaps.

Animal category	Type of store	CH_4 emission (kt)	% CH_4 loss from stores	N_2O emission (kt)	% N_2O loss from stores
Cattle	Solid manure Slurry stores	32.6 1.9	77.9 4.5	3.58 0.0	63.4 0.0
Sheep	Solid manure	1.0	2.4	0.12	2.1
Pigs	Solid manure Slurry store	1.9 3.6	4.5 8.6	0.05 0.0	0.9 0.0
Poultry	Solid manure	0.9	2.1	1.90	33.6
Deer	Solid manure	0.0	0.0	0.0	0.0
Total		39.0	100.0	5.65	100.0

Table 2.
CH_4 and N_2O emissions from manure stores in the UK.

Land spreading

Emissions of CH_4 and N_2O following land spreading manures are summarised in Table 3. The N_2O and CH_4 losses following landspreading of manures are relatively small with the greatest losses coming from the spreading of cattle manures. The average % N lost as N_2O following applications of pig and dairy slurries were 0.4% and 0.3%, respectively. These values are similar to those reported by Paul *et al.* (1993) and Sommer *et al*. (1996). Methane losses were very short–lived following manure application as oxygen diffused into the manures.

Animal category	Type of store	CH_4 emissions (kt)	% CH_4 loss from spreading	N_2O emission (kt)	% CH_4 loss from spreading
Cattle	Solid manure Slurry	0.2 0.1	40.0 20.0	0.52 0.30	46.8 27.1
Sheep	Solid manure	<0.1	<0.1	0.03	2.7
Pigs	Solid manure	0.2	40.0	0.03	2.7

	Slurry	<0.1	<0.1	0.13	11.7
Poultry	Solid manure	<0.1	<0.1	0.10	9.0
Deer	Solid manure	<0.1	<0.1	<0.01	0.0
Total		0.5	100.0	1.11	100.0

Table 3.
N_2O and CH_4 emissions following manure spreading in the UK.

Emissions from grazing and outdoor animals

The greatest CH_4 emission was from the enteric fermentation of grazing ruminants, 306.0 kt from cattle and 125.1 kt from sheep. The greatest N_2O emission was also from grazing cattle, 3.17 kt, but as a result of the nitrification and denitrification of N returned to the soil in dung and urine.

Conserved grassland and tillage land

These areas of land were considered not to be emitters of methane. There is evidence of CH_4 uptake by grasslands but this has not been considered in this inventory. The annual N_2O emissions from different fertiliser types totalled 2.05 kt for conserved and grazed grassland and 3.01 kt for tillage land.

Total emissions

Emissions from components of farm management are shown in Table 4. The largest components in the total emission of N_2O are manure stores, 5.65 kt and fertilised land, 5.36 kt. The largest components in the total emission of CH_4 are housing and outdoor livestock, i.e. enteric fermentation in ruminants.

Component	CH_4 emission (kt)	% CH_4 of total loss	N_2O emission (kt)	% N_2O of total loss
Housing	371.3	44.0	4.99	23.6
Storage	42.0	4.9	5.65	26.8
Land application	0.5	<0.1	1.11	5.3
Fertiliser	0.0	0.0	5.36	25.4
Outdoor livestock	431.6	51.1	3.98	18.9
TOTAL	845.5	100.0	21.09	100.0

Table 4.
CH_4 and N_2O emissions by farm management in the UK.

When the inventories are broken down by livestock class (Table 5), the largest proportion of the total N_2O emission is from cattle (44.4%) followed by poultry (23.9%) and the largest proportion of the total CH_4 emission is also from cattle (81%).

Component	CH_4 emission (kt)	% CH4 of total loss	N_2O emission (kt)	% N_2O of total loss
Cattle	684.0	81.0	9.36	44.4

Sheep	130.7	15.5	0.75	3.6
Pigs	27.7	3.2	0.39	1.8
Poultry	2.7	0.3	5.04	23.9
Deer	0.3	<0.1	0.19	0.9
Conserved grassland	0.0	0.0	2.05	9.7
Tillage land	0.0	0.0	3.31	15.7
TOTAL	845.4	100.0	21.09	100.0

Table 5.
CH_4 and N_2O emissions by livestock class in the UK.

4. Discussion

N_2O

The N_2O inventory described above identifies three sub-terms not included in earlier inventories, namely emissions from outdoor livestock, from livestock buildings and from stored manures. Nevertheless, the total annual emission is in the range of those emissions of HMSO (1997b), 9.90 kt, and Croxford (1994 unpublished MAFF work), mean of 14.32 kt (range 1.99-155.13) but much lower than that by Armstrong Brown *et al*. (1996), 103 kt.

The largest term according to inventories of Croxford (unpublished MAFF figures for 1994) and of HMSO (1997b), is the N_2O emission from soils receiving mineral N fertilisers, whereas the inventory of Armstrong-Brown *et al*. (1996) indicated that N_2O emissions from land applications of manures is the largest term. This difference arises because of the different expressions used for predicting N_2O losses from these sources, viz. that up to 7.8% of the ammoniacal-N (NH_4^+-N) content of manure is emitted as N_2O-N (Jarvis and Pain, 1994) which may be a worst case scenario. From the 20 sets of field measurements made following land spreading of manures during our study the average values for the percentage of manure-NH_4^+-N lost as N_2O-N were 0.64 % for slurries (n=15) and 5.90 % for solid manures (n=5).

The inventory total is very sensitive to changes in the %N lost as N_2O from soil fertilised with inorganic N fertilisers. We used the average figures for different N fertiliser types quoted by Eichner (1990) but, because of the effect of complex interactions of physical, chemical and biological variables on N_2O production and emissions from soils, the accuracy of this approach is questionable. (Bouwman, 1990). Soil management and cropping regimes and variable rainfall may have a greater effect on N_2O emissions than fertiliser type. Therefore, Bouwman (1996) recommended the use of one emission factor to cover all N fertiliser types. i.e. 1.25% of N applied (kg N ha^{-1}). If this emissions factor is used the total N_2O loss from conservation and tillage land increases from 5.36 kt y^{-1} to 23.90 kt y^{-1} and the annual N_2O loss for UK farmed livestock increases from 21.09 kt to 39.63 kt.

The N_2O losses from grazing cattle (excretal returns) were taken from Yalmulki *et al*. (1998) who found that up to 1% of the N excreted in urine and 0.53% excreted in the dung were emitted as N_2O, respectively. A recent review by Oenema *et al*. (1997) suggests that, on average, 2% of excreted N is emitted as N_2O. Using this value in our inventory increases the total loss for grazing cattle from 3.1 kt to 7.0 kt. This term also includes the influence of soil compaction on N_2O emissions. Using the same value for the fractional loss, i.e. 2%, the N content of the excreta and the excretal rate, the N_2O emissions from outdoor pigs, initially estimated from the fractional loss following slurry applications to land, are increased from 0.03 kt to 0.20 kt. The N_2O emission estimated from grazing sheep is also increased from 0.29 kt to 1.94 kt per year using this EF of Oenema *et al.* (1997).

Our inventory was constructed in a relatively simple format with no direct consideration of the effect of the time of year, animal diet or soil type on emission factors, although we recognise that such factors are important e.g. Velthof and Oenema (1995). We used values which were based on the means of measurements taken from animal buildings, manure stores and following manure applications to the land throughout the year and which covered a range of typical animal diets, soil types and slurry application techniques. Because of the approach we estimate the error associated with the total N_2O emissions to be ± 50%.

CH_4

The CH_4 inventory was dominated by emissions from enteric fermentation in cattle. Our value for this EF, 270 g lu^{-1} d^{-1}, for dairy (milking) cattle is based on the arithmetic mean of both long-term measurements (5 weeks) and many short-term (24 hours) measurement periods at commercial farms in the UK. It is evident from the literature that within any one class of cattle, differences in measured CH_4 emission rates are evident. This may be due to differences in measurement methods but it is known that diet effects enteric CH_4 production and also there appears to be an animal to animal variation in CH_4 emission rate, so measurements on large groups of animals are more desirable than measurements on single animals. Our total of 845.0 kt is somewhat lower than that of earlier authors. Moss (1993) considered only enteric fermentation in her inventory, 1,420 kt, with no allowance for CH_4 from slurries or manures. Moreover she took only literature values for the production rates of CH_4 by different livestock classes (from Crutzen *et al*., 1996) rather than making direct measurements.

Abatement practices

Potential abatement practices to reduce N_2O emissions from housing and storage facilities could involve moves from straw based cattle systems to slurry based systems. The anaerobic nature of slurry stores would reduce N_2O emission considerably, but possibly, at the expense of increased CH_4 emissions unless preventative actions were taken. A further ‘upstream’ management strategy would be to reduce N excretion by feeding animals diets more closely related to their nutritional requirements. This hypothesis was proved by Hobbs *et al*. (1996). Spreading the resulting slurry from pigs fed a modified diet onto grassland resulted in significantly lower emissions of NH_3, CH_4 and denitrification losses and better utilisation of slurry NH_4^+-N compared with an application of slurry from conventionally fed pigs

(Misselbrook *et al*., 1998). Methane emissions from the rumens of cattle can also be influenced by diet. Recent work at IGER has demonstrated significantly lower CH_4 emissions from beef cattle fed silage maize than the same cattle fed grass silage or hay based diets (unpublished data).

Restrictions on time and rate of application offer the potential for further reducing N_2O emissions following fertiliser-N and manure applications (Chadwick, 1997). Soil mineral-N levels should be kept at an optimum level for crop requirements and reduced to a minimum at times of low crop demand, e.g. in autumn and early spring when soil conditions are favourable for denitrification.

Reductions in N_2O emissions from grazed pasture would arise from increasing the productivity per animal with a concurrent decrease in animal numbers, dietary control of N excretion and restricted grazing.

5. Conclusions

Our estimate of N_2O emission for UK livestock production in 1996 is 21.1kt ± 50%. The largest terms are manure stores (5.65 kt), where 99% of N_2O emissions arise from solid manure heaps, and soils fertilised with inorganic N fertilisers (5.36 kt). Our estimated emission from fertilised soils may be conservative. Also, more recent data suggest that losses of N_2O from grazed pasture, particularly cattle, may have a large influence on the total emission. If we include estimated emission factors for grazed land (Oenema *et al.*, 1997) and the greater fractional loss value for fertilised soils, 1.25%, quoted by Bouwman (1996) we increase the total emission to approximately 45.2 kt a^{-1}. Our estimated CH_4 emissions is 845.0 kt, 80% of which is from cattle and 15% from sheep. Over 90 % of all the CH_4 emitted in our inventory is from enteric fermentation.

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