Inventory of Ammonia Emissions from UK Agriculture

2008

DEFRA Contract AC0112

Inventory Submission Report
November 2009

T H Misselbrook, D R Chadwick, S L Gilhespy
North Wyke Research,
North Wyke, Okehampton, Devon EX20 2SB

B J Chambers[1], K A Smith[2] and J Williams[3]
[1] ADAS Gleadthorpe, Meden Vale, Mansfield, Nottingham NG20 9PF
[2] ADAS Wolverhampton, Woodthorne, Wergs Road, Wolverhampton WV6 8TQ
[3] ADAS Boxworth, Battlegate Road, Boxworth, Cambridge CB3 8NN

U Dragosits
CEH Edinburgh, Bush Estate, Penicuik, Midlothian EH26 0QB

Inventory of Ammonia Emissions from UK Agriculture – 2008

Summary

The National Ammonia Reduction Strategy Evaluation System (NARSES) model (spreadsheet version) was used to estimate ammonia (NH_3) emissions from UK agriculture for the year 2008. Year-specific livestock numbers and fertiliser N use were added for 2008 and revised for previous years. The estimate for 2008 was 229.5 kt NH_3, representing a 12.6 kt decrease from the previously submitted estimate for 2007. Excluding the effect of historical revisions to livestock numbers, this represented a real year on year decrease of 13.3 kt NH_3. Backward and forward projections using the 2008 model structure gave estimates of 318, 243 and 242 kt NH_3 for the years 1990, 2010 and 2020, respectively. This inventory reports emission from livestock agriculture and from nitrogen fertilisers applied to agricultural land. There are a number of other minor sources reported as 'agriculture' in the total UK emission inventory, including horses not kept on agricultural holdings, emissions from composting and domestic fertiliser use.

Table 1. Estimate of ammonia emission from UK agriculture for 2008

Source		**kt NH_3**	**% of total**
Livestock category			
Cattle		132.0	57
	Dairy	*70.2*	*31*
	Beef	*61.7*	*27*
Sheep[†]		10.7	5
Pigs		19.8	9
Poultry		30.7	13
Horses		4.7	2
Management category			
Grazing/outdoors		29.5	13
Housing		63.0	27
Hard standings		22.2	10
Manure storage		30.5	13
Manure application		52.5	23
Fertiliser application		31.8	14
TOTAL		**229.5**	

[†]Including goats and deer

Estimate of ammonia emission from UK agriculture for 2008

The estimate of ammonia emission from UK agriculture for 2008 was made using the spreadsheet version of the National Ammonia Reduction Strategy Evaluation System (NARSES) model (file: NH3inv2008_NARSES_final1_151109.xls). NARSES models the flow of total ammoniacal N (TAN) through the livestock production and manure management system, with NH_3 losses given at each stage as a proportion of the TAN present within that stage (Webb and Misselbrook, 2004). NARSES was first used to provide the 2004 inventory estimate for UK agriculture, replacing the previously used UK Agricultural Emissions Inventory model (UKAEI). NARSES brings improvements over the UKAEI model in that emission sources are linked, such that changes in an upstream source will be reflected downstream, it has an internal accounting check that not more than 100% of TAN excreted can be emitted, it can incorporate rising trends in N excretion by certain livestock classes (e.g. dairy cattle) and it is much better suited to scenario testing. The NARSES model was therefore used to provide the NH_3 emissions estimate for UK agriculture for 2008 and projections to 2020.

To compile the 2008 inventory of ammonia emissions from UK agriculture, survey and census data were reviewed to derive livestock numbers, fertiliser use and other management practice data relevant to 2008. Currently used emission factors were reviewed in the light of new experimental data and amended if considered appropriate.

Key areas of revision in the 2008 inventory were:

- Revision of historical livestock numbers 1990 - 2007
- Inclusion of 2008 fertiliser use data
- Inclusion of 2008 livestock numbers

Derivations of emission factors and other data used in NARSES are detailed in Appendix 1.

The estimate of emission from UK agriculture for 2008 was 229.5 kt NH_3. Cattle represent the largest livestock source and housing and land spreading the major sources in terms of manure management (Table 1).The effect of sequential changes made to the inventory during the revision for 2008 are detailed below, with the impact on the total shown in Table 2. A breakdown of the estimate is given in Table 3, together with a comparison with the previously submitted 2007 inventory estimate.

Table 2. Sequential influence of revisions to individual components on the inventory total (NARSES model) during the 2008 revision

	Change ($kt\ NH_3$)	Total ($kt\ NH_3$)
2007 total		**242.1**
Fertiliser use activity data 2008	-7.9	
Revision of livestock numbers 2007	+0.7	
Livestock numbers 2008	-5.4	
2008 total		**229.5**

Table 3. Estimate of ammonia emissions ($kt\ NH_3$) from UK agriculture, 2008

Source	2007	2008	Reasons for change
Cattle			Reduction in cattle numbers
Grazing	15.9	**15.6**	
Landspreading	33.6	**33.2**	
Housing	40.2	**39.5**	
Hard standings	21.8	**21.3**	
Storage	22.6	**22.3**	
Total Cattle	134.0	**132.0**	
Sheep (incl. Goats & Deer)			Reduction in sheep numbers
Grazing	7.8	**7.6**	
Landspreading	0.2	**0.2**	
Housing	1.2	**1.2**	
Hard standings	0.9	**0.9**	
Storage	0.9	**0.8**	
Total Sheep	11.0	**10.7**	
Horses	4.9	**4.7**	Reduction in horse numbers
Pigs			Reduction in pig numbers and N excretion
Outdoor	0.9	**0.8**	
Landspreading	4.6	**4.4**	
Housing	10.4	**9.9**	
Hard standings	0.0	**0.0**	
Storage	5.0	**4.7**	
Total Pigs	20.9	**19.8**	
Poultry			Reduction in poultry numbers and N excretion
Outdoor	0.8	**0.8**	
Landspreading	15.2	**14.8**	
Housing	13.0	**12.5**	
Storage	2.7	**2.6**	
Total Poultry	31.7	**30.7**	
Fertiliser	39.7	**31.8**	Reduction in total N use, reduction in proportion as urea
TOTAL	242.1	**229.5**	

Major changes between 2007 and 2008

1. Historical revisions to livestock numbers

Livestock numbers from 1990 – 2007 were revised according to the statistics provided by each of the Devolved Administrations (i.e. England, Wales, Scotland and Northern Ireland). Some discrepancies remain between UK statistics and totals of those provided by the DAs; the reasons for these will be explored further during the coming year.

2. 2007 fertiliser use data

Date derived from BSFP for crop year 2008 for England, Wales and Scotland and from DARDNI statistics for Northern Ireland. NB – there has been a reduction in the number of fertiliser types listed in Table EW3.2 and an equivalent table for Scotland is no longer published (but can be derived by subtracting EW3.2 from GB3.2).

Total fertiliser N use was down by 10% on 2007, and urea use decreased by 48%, giving an overall reduction in emissions of 7.9 kt NH_3.

3. 2007 livestock numbers

Headline changes from 2007 are:

Cattle – a 2% decline in total cattle numbers (across both the dairy and beef herd)

Pigs – a 3% decline in pig numbers

Sheep – a 3% decline in sheep numbers

Poultry – a 1% decline in total poultry numbers, with a 5% decline in the laying flock but a 1% increase in broiler numbers

Past and Projected Trends: 1990 - 2020

Retrospective calculations based on the 2008 inventory methodology were made for the years 1990 to 2008 and projections for the years 2010, 2015 and 2020 (Table 4). Projected changes in livestock numbers, N fertiliser use and management practices are detailed below. There has been a steady decline in emissions (28%) from UK agriculture over the period 1990 – 2008, largely due to declining livestock numbers (Fig. 1) and fertiliser N use (Fig. 2). The decline is projected to level off, with an estimated 24% reduction from 1990-2020. These projections are subject to much uncertainty and further work is required to both generate more robust projections in agricultural activity data and an estimate of uncertainties relating to the assumptions made in deriving the projections.

Table 4. Estimates of ammonia emission from UK agriculture 1990 – 2020 using the NARSES model

Source	1990	1995	2000	2005	2008	2010	2015	2020
						Projections		
Total	**317.5**	**291.6**	**265.7**	**248.9**	**229.5**	**242.7**	**243.1**	**241.7**
Cattle	154.7	150.8	144.2	137.9	132.0	133.3	131.3	130.6
Dairy cattle	*81.7*	*77.6*	*73.7*	*70.0*	*70.2*	*74.6*	*73.9*	*74.5*
Other cattle	*72.9*	*73.2*	*70.5*	*67.9*	*61.7*	*58.6*	*57.4*	*56.1*
Sheep	14.2	14.1	13.7	11.6	10.7	11.5	11.4	11.3
Pigs	42.6	39.8	31.3	22.0	19.8	19.9	19.2	18.4
Laying hens	13.7	11.9	10.0	9.5	7.9	9.1	9.0	8.6
Other poultry	26.1	24.5	29.1	25.3	22.7	25.7	25.7	25.8
Horses	2.6	3.4	3.7	4.4	4.7	5.1	5.8	6.5
Fertiliser	63.7	47.1	33.7	38.1	31.8	38.2	40.8	40.5

Figure 1. Trends in livestock numbers 1990 – 2020. Changes are relative to a reference value of 100 in 1990. Dashed lines show projections from Defra project SSF0601.

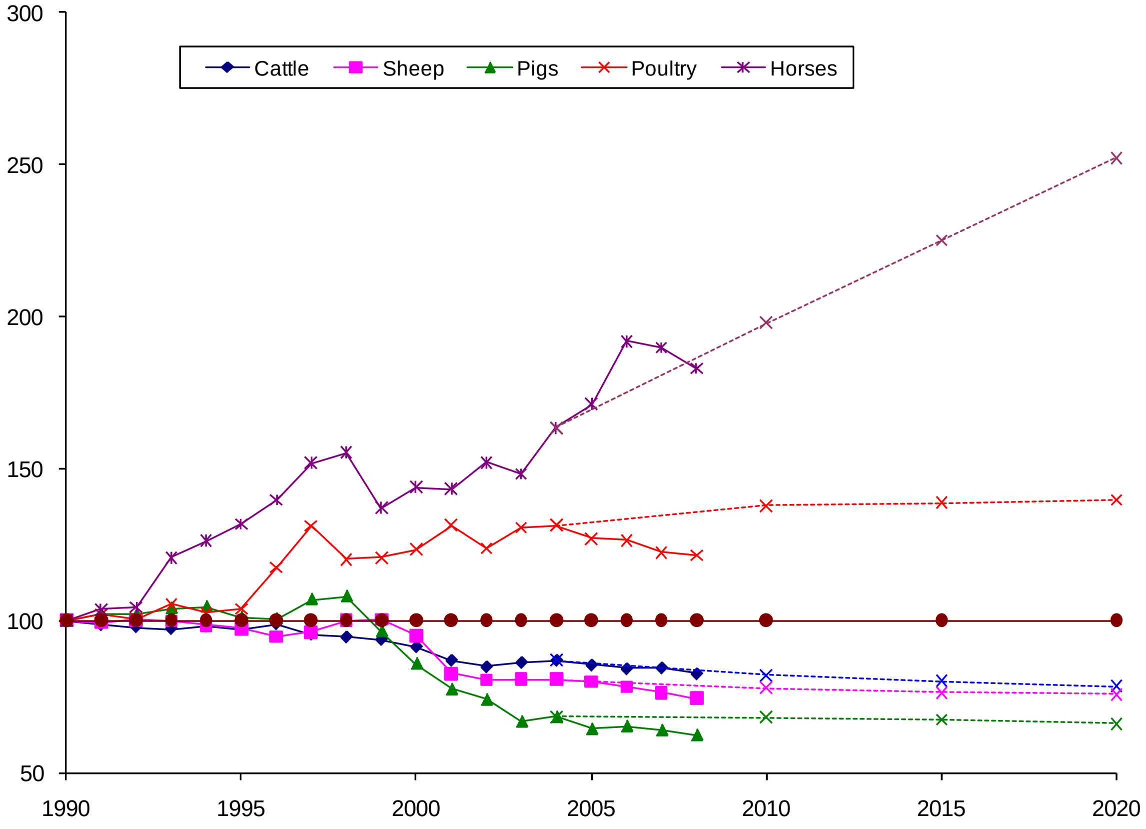
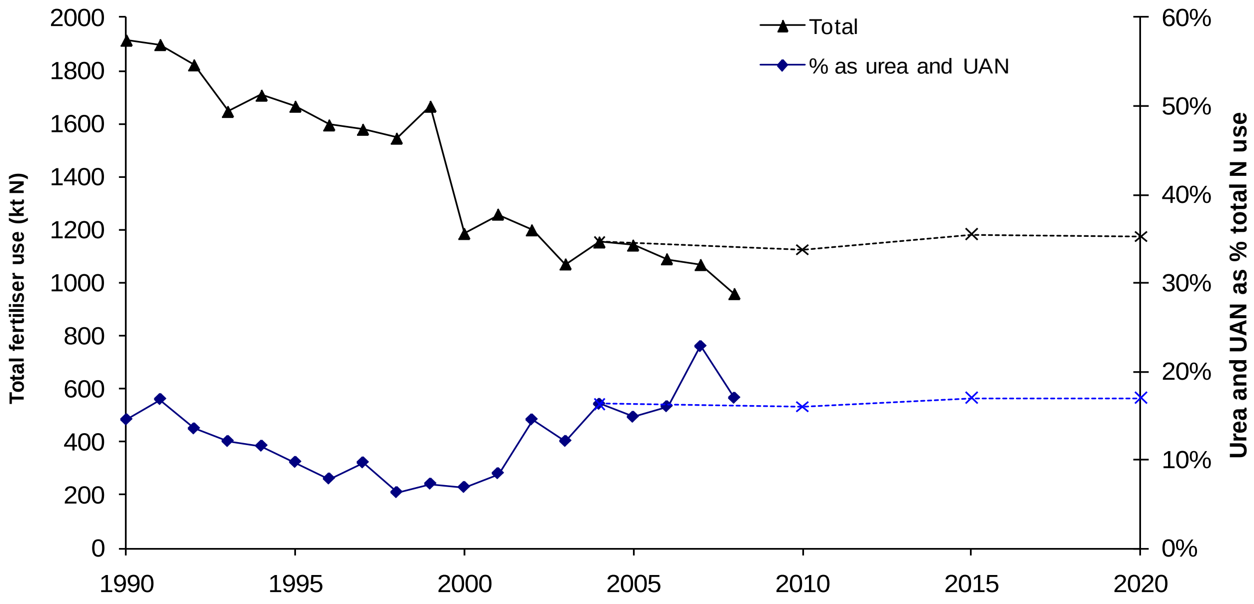


Figure 2. Changes in fertiliser N use 1990 – 2020. Dashed lines show projections from Defra project SSF0601.



Projections – methodology and assumptions

Livestock numbers

Livestock number projections were based on projections made in Defra project SFF0601 (Baseline projections for Agriculture), using June 2004 census data as the base year. These projections tended not to give such large reductions in livestock numbers (cattle and sheep, in particular) as were projected under the Business as Usual II project (UoC/SAC). In addition, trends in N excretion were included: N excretion by dairy cattle was forecast to increase as cattle numbers became fewer but milk quota was maintained. N excretion by certain pig and poultry categories were forecast to decrease as dietary improvements were taken up by the industry. Past and projected trends in livestock numbers use are shown in Figure 1. Generally, livestock numbers from 2005 to 2008 are below the projected values, particularly for poultry.

Fertiliser use

Fertiliser use projections were also taken from Defra project SFF0601, using 2004 data as the base year. Again, less substantial reductions in fertiliser use are projected than in the BAUII project (indeed, an increase in total N use to tillage is projected), partly as increasing areas of biofuel cropping were factored in and also as reductions in N applications to grassland were thought not to be sustainable if past trends were simply continued. Proportions of each fertiliser type applied were assumed to remain the same. Past and projected trends in fertiliser N use are shown in Figure 2. Total fertiliser N use has declined by more than projected from 2004 to 2008.

Farm management practices

Trends in changes in farm management practices (*e.g.* type and duration of livestock housing, manure storage and application methods) are difficult to quantify as there are relatively few surveys from which to obtain relevant data and those surveys which have been conducted are not always directly comparable. It is hoped that regular and consistent running of the Farm Practices Survey will be able to provide estimates of such trends in the future. For the default scenario, therefore, it has been assumed that no changes will take place in management practice in the absence of legislation or incentive schemes. IPPC legislation will impact on the practices of large pig and poultry farms from 2007 onwards; the assumptions regarding changes in livestock housing and manure management due to IPPC legislation are detailed earlier in this report.

Emission factors

Emission factors as used in the current model were kept constant for all model runs from 1990 – 2020.

Uncertainties

An analysis of the uncertainties in the emission inventory estimate was conducted by Webb and Misselbrook (2004) using @RISK software (Palisade Europe, London), in which a distribution was attached to each of the model inputs (activity or emission factor data), based on the distribution of raw data or, where no or only single estimates exist, on expert assumptions. A large number of model runs (2000) were then conducted in which input values were selected at random from within the given distribution (Latin hypercube sampling) and an uncertainty limit produced for each of the model outputs. The 95% confidence interval for the total inventory estimate was estimated to be ±20% (i.e. ±468 kt NH_3 for the 2008 estimate).

APPENDIX 1

DERIVATION OF EMISSION FACTORS FOR THE INVENTORY OF AMMONIA EMISSIONS FOR UK AGRICULTURE

NB: Derivation of emission factors as used in the previous inventory model (UKAEI) and in the currently-used NARSES model are given.

All emission factors (EF) are given in terms of NH_3-N or, where expressed as a percentage, these are as a % TAN (total ammoniacal nitrogen) within the current ‘emission pool’ (e.g. losses at spreading are expressed as %TAN in the manure at spreading).
Cited sources are either scientific publications or Defra project Final Reports (given by Project Code), which are available from the Defra web-site.

CATTLE

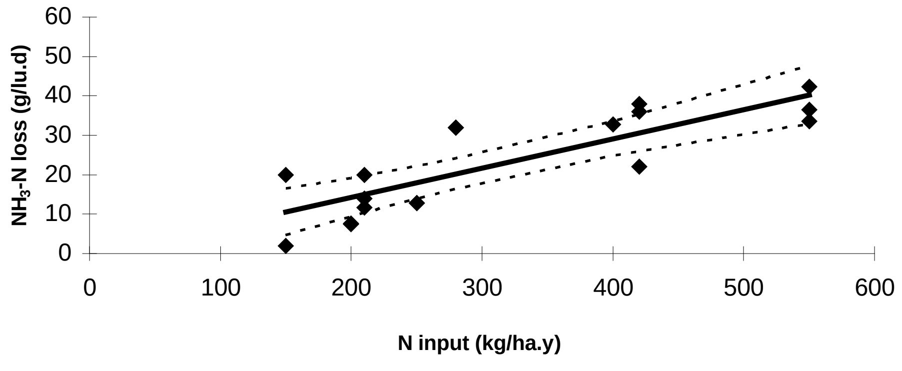
Grazing

UKAEI

- A updated version of the relationship between N input (kg N/ha) and ammonia emission (g N lu^{-1} d^{-1}) from cattle grazed swards (Jarvis & Bussink 1990) was used, including data from Jarvis *et al*. 1989, Bussink 1992 and 1994, Ledgard 1996 and IGER (OC9117).

N input	Jarvis *et al*. '89	Bussink '92	Bussink '94	Ledgard '96	IGER OC9117	WA0652
150	2					
150	20					
200						7.5
200						7.7
210	20					
210	14			11.64		
250		12.73	12.73			
280					32	
280					32	
400			32.73			
420	38					
420	36					
420	22					
550		42.27	33.64			
550		36.54				

Ammonia emission from cattle grazing - fitted relationship with upper and lower 95% confidence intervals



Fitted relationship: $y = -0.51+0.0742\,x$ (r^2 0.68)

NARSES

EF for NARSES was derived from source data, where sufficient data were available. Emissions due to the fertiliser applied to the grazed pasture were discounted using a mean EF for ammonium nitrate applications to grassland (1.4% of N applied). The remaining emission was expressed as a percentage of the estimated TAN return to the pasture via cattle urine.

Bussink	Fert Res 33 257-265					
	N input	Urine N	NH3 emission	Due to fert	Due to urine	%TAN
1987	550	425	42.2	7.7	34.5	8%
1988	550	428	39.2	7.7	31.5	7%
1988	250	203	8.1	3.5	4.6	2%
Bussink	Fert Res 38 111-121					
	N input	Urine N	NH3 emission	Due to fert	Due to urine	%TAN
1989	250	64.2	3.8	3.5	0.3	0%
1989	400	76.2	12	5.6	6.4	8%
1989	550	94.3	14.7	7.7	7	7%
1990	250	217.4	9.1	3.5	5.6	3%
1990	400	339	27	5.6	21.4	6%
1990	550	407.1	32.8	7.7	25.1	6%
Lockyer	J Sci Food Agric 35, 837-848					
	Urine applied	Emission				%TAN
1	26	0.6455				2%
2	26	0.7025				3%
Jarvis et al	J Ag Sci 112, 205-216					
	N input	Urine N	NH3 emission	Due to fert	Due to urine	%TAN
1986/87	0	69	6.7	0	6.7	10%
1986/87	210	81	9.6	2.94	6.66	8%
1986/87	420	207	25.1	5.88	19.22	9%

An overall mean EF of 6 %TAN was derived.

Land spreading

NARSES

Slurry

- EF derived from the MANNER_PSM model (KT0106)

The ‘standard’ EF for cattle slurry is given as 32.4 %TAN applied, which is then modified according to soil moisture, land use and slurry dry matter (DM) content at the time of application:

a) soil moisture (‘season’):

Dry (summer) EF_1 = ‘standard’ EF x 1.3
Moist (rest of year) EF_1 = ‘standard’ EF x 0.7

b) land use:

Grassland $EF_2 = EF_1 \times 1.15$
Arable $EF_2 = EF_1 \times 0.85$

c) slurry DM content

$$EF_3 = EF_2 \times ((12.3 \times DM)+50.8)/100$$

<u>Abatement techniques</u>
Injection - abatement efficiency of 70% (assumed to be shallow injection)
Trailing shoe – abatement efficiency of 60%
Band spreading – abatement efficiency of 30%
(Misselbrook *et al.*, 2002; Smith *et al.*, 2000b)

Incorporation
Incorporation within 4h gives 60% reduction
Incorporation within 24h gives 30% reduction
Values derived from using MANNER PSM (Project KT0106), assuming incorporation by plough.

FYM

- EF derived from the MANNER_PSM model (KT0106) as 68.3 %TAN applied. No modifiers for soil, manure or weather.

Abatement – incorporation
Incorporation within 4h gives 70% reduction
Incorporation within 24h gives 35% reduction
Values derived from using MANNER_PSM (Project KT0106), assuming most incorporation by plough.

Housing

Mean EF g N $lu^{-1}d^{-1}$	Values g N $lu^{-1}d^{-1}$	Derived from n values	Emission as % TAN	Source
Slurry (cubicle house)				
36.8	38.5		29.4	Demmers *et al*. (1997)
	29.0	9	19.9	WA0653
	43		42.4	Dore *et al*., (2004)
	51	3	*57.0	WA0632/AM0110 (Polytunnels)
	29.4	1	51.0	Hill (2000)
	30		29.6	AM0102 (commercial farm)
Straw-bedded				
22.2	13.7			Demmers (1997)
	20.6		NA	WA0618 (IGER polytunnels)
	35	3	*56.0	WA0632/AM0110 (Polytunnels)
	33.2		47.0	WA0722
	13.9		18.4	AM0103 (IGER polytunnels)
	16.7		14.0	AM0103 (commercial farm)
Calves				
10.6	10.6		7.0	Koerkamp *et al*., 1998
	13.7		11.0	Demmers (1997)

NARSES EF were calculated from standard values for N excretion in buildings, except for those results marked with an asterisk for which data were available on diets and liveweight gain during the measurement period to allow calculation of actual N excretion. The NARSES EF, using a mean weighted according to the number of measurements reported are 31.5, 22.9 and 7.6 % TAN for cattle on slurry, cattle on straw and calves on straw respectively.

No distinction is made between dairy and beef cattle housing emission factor. Values from IGER (WA0632) and IGER (WA0618) refer to beef cattle; all others are for dairy cattle.
CAMAR data was not used (with exception of calves), as there were doubts about the methodology of measurements from naturally ventilated buildings.

The value for cattle on cubicles from SRI (Dore *et al*., 2004) excludes measurements made by the external tracer method. The data for the 3rd year of WA0653 was not used; measured emissions were very much lower than for the first 2 years, with several negative values for individual sampling points and dates, although there were no obvious explanatory factors.

Work by Phillips *et al*. (1998) suggests that summer emissions from dairy cattle housing, where the cattle come in for part of the day for milking, may be of a similar magnitude to winter emissions. An EF for summer housing emissions is not explicitly included in the inventory, but housing period is increased to account for the hours each day during the summer when the cattle are in. The EF for housing is likely to be greater in summer, because of higher temperatures. However, it is also likely that the floor area from which emission take place will be much reduced, as access to housing may be restricted.

Hard standings

UKAEI
Data from AM0111, incorporating data from Misselbrook *et al*., (1998, 2001)

Source	Means EF (g N $animal^{-1}$ d^{-1})
dairy cow collecting yard	10.7
dairy cow feeding/loafing yard	10.7
beef feeding/loafing yard	23.3

Emission factors were expressed per animal rather than per m^2 surface area because annual changes in livestock numbers are known with much greater certainty than changes in areas of hard standing.

For NARSES, the following data/assumptions were used: Survey data, collected as part of project WA0504, indicate that 65% of dairy cattle have access to collecting yards and 30% have access to feeding yards while 45% of beef cattle have access to feeding yards. Survey data from FPS2006 indicates that dairy cows with access to collecting yards spend an average of 33% of the day on the yards, so the amount of excreta deposited is assumed to be pro-rata to the time spent. Data from project NT2601 indicate that 21% of daily N excretion is deposited on feeding yards by dairy cattle which have access to them. Expert opinion was that approximately 40% of daily excreta from beef cattle on feeding yards is deposited to the yard (FPS2006 indicates that the animals have access for the majority of the day, but they would also have access to housing during this period). Project AM0111 indicated that collecting yards, which are scraped at least once a day, are scraped with an efficiency of c. 60%. Based on Misselbrook et al (2006) it is assumed that 75% of the TAN left after scraping is emitted as NH_3. For feeding yards, which are scraped only once or twice a week on average, the scraping efficiency is assumed to be 30%.

Storage

Mean EF g N $m^{-2}d^{-1}$	Values g N $m^{-2}d^{-1}$	Derived from n values	Emission as % TAN	Source
Slurry stores and lagoons without crusts				
3.42				Assumed to be double that for crusted stores (WA0641, WA0714)
Slurry stores and lagoons with crusts, weeping wall stores				
1.71	0.6		**2.3	(Phillips *et al*., in press)
	1.27, 3.65, 5.7		NA	WA0625
	0.44	2	*6.0	WA0632*
	1.8		NA	WA0641
	1.7		NA	Hill (2000)
	0.48	2	NA	WA0714
	0.5,0.72,0.42,0.73		51.5 (lagoons) 5.3 (w.wall)	WA0717
	4.2		NA	AM0102
FYM heaps	**g N t^{-1} initial heap mass**			
265	421, 101, 106		NA	WA0618
	65, 618, 889		95.0	WA0519
	305, 140		22.0	WA0632
	250, 36, 26		12.0	WA0707

** Emissions expressed per day. This value assumes 90 d storage.

Slurry stores are assumed to develop a crust unless they are stirred frequently.
Values derived from measurements made using Ferm tubes have been corrected to account for incomplete recovery of ammonia by Ferm tubes (Phillips *et al*., 1998). (*IGER values have been divided by **0.7**).

Emissions from FYM stores were previously based on surface area. However, it was considered that the estimates of store surface areas (Nicholson and Brewer survey, 1994) seriously underestimated solid manure storage areas (possibly because of multiple use of the same area or not accounting for short-term storage heaps). Therefore emissions are now calculated on a per tonne basis (using data from the same experimental studies).

NARSES EF were derived as a weighted mean of those studies which supplied information on the amounts of N and TAN put into store. Mean EF were derived as 5.0 and 51.5 % TAN for tanks (assumed to be crusted and equivalent to weeping wall store) and lagoons, respectively. For FYM a weighted mean EF of 35% was derived.

<u>SHEEP</u>

Grazing

UKAEI

- Upland sheep based on values from Jarvis *et al*. (1991) 0N, and grass/clover plots. Mean values for the 2 years were 0.92 and 0.19 g N animal^{-1} d^{-1}, giving a mean EF of 0.56 g N animal^{-1} d^{-1}.
- Lowland sheep based on values from Jarvis *et al*. (1991) - 420N, clover and grass clover plots giving mean values over 2 yrs of 1.05 and 1.16 g N animal^{-1} d^{-1}- and on new IGER unpublished data from North Wyke with values of 1.36, 3.95, 2.47, 0.89, 3.11 and 1.78 g N animal^{-1} d^{-1}. Overall mean gives an EF of 2.0 g N animal^{-1} d^{-1}.
- EF for grazing lambs taken to be half the value for sheep, as lamb excretal output is approximately half that of sheep.

NARSES

Insufficient data regarding N returns to the pasture by grazing sheep were available from the source publications listed above, so the EF used for cattle grazing (6 %TAN) was assumed for sheep.

Land spreading

- FYM - value for cattle used.

Housing

NARSES EF was derived directly by back-calculation of the UKAEI, giving an EF of 21.6% TAN, since there are no reported measurements of NH_3 emission from buildings housing sheep.

Hard standings

UKAEI

A mean emission factor of 5.0 g N animal^{-1} d^{-1} derived from data from 2 sites (7.20 and 2.82 g NH_3-N animal^{-1} d^{-1}) from Misselbrook *et al*., 2001.

NARSES

Sheep collecting yards are scraped infrequently, if at all, so a scraping efficiency of 0% was applied and an EF of 75% TAN deposited.

Storage

- FYM - value for cattle used.

PIGS

Outdoors

	Mean EF g N $lu^{-1}d^{-1}$	Values g N $lu^{-1}d^{-1}$	Emission as %TAN	Source
Outdoor sows/piglets	**46**	25	26.1	Williams et al. (2000)
		66*	NA	Welch (2003)

*This value is probably an overestimate as emission rates were below the detection limit on a number of occasions (and those data were not included).

Emission factor for boars assumed to be the same. For fatteners, EF is based on the ratio of excretal outputs multiplied by the emission factor for outdoor sows.

NARSES EF was derived from the Williams et al (2000) study, assuming the standard N excretion value for sows and a body weight of 200kg, giving a mean EF of 25 %TAN (assumed to be the same across all animal sub-categories).

Land spreading

Slurry

- EF derived from the MANNER_PSM model (KT0106)

The 'standard' EF for pig slurry is given as 25.5 %TAN applied, which is then modified according to slurry dry matter (DM) content at the time of application:

a) slurry DM modifier:

$$EF_1 = \text{'standard' EF x ((12.3 x DM)+50.8)/100}$$

FYM

The same EF as for cattle FYM is used, 68.3 %TAN applied

<u>Abatement techniques</u>

Slurry injection – abatement efficiency of 90% (assumed to be deep injection to arable land)
Band spreading (trailing hose) – abatement efficiency of 30%

Incorporation
Incorporation within 6h gives 60% reduction
Incorporation within 24h gives 30% reduction
Values derived from using MANNER PSM (Project KT0106), assuming most incorporation by plough

Housing

Mean EF ($gN.lu^{-1}d^{-1}$)	Values ($gN.lu^{-1}d^{-1}$)	Derived from n values	Emission as %TAN	Source
Dry sows on slats				
17.0	17.0	2	13.0	Peirson (1995)
Dry sows on straw				
25.8	9.4	2	10.0	Peirson (1995)
	14.6		14.7	Koerkamp *et al.*, 1998
	26.2	4	26.2	OC9523
	53		59.6	AM0102
Farrowing sows on slats				
29.3	32.4	3	19.0	Peirson (1995)
	20.6		14.3	Koerkamp *et al.*, 1998
	35		24.0	AM0102
Farrowing sows on straw				
44.5				Estimated from ratio of EF for dry sows
Boars on straw				
25.8				As for dry sows
Fatteners >20kg on slats				
71.9	70.1		20.0	Peirson (1995)
	51.4		18.5	Koerkamp *et al.*, 1998
	105.8		38.2	Demmers (1997)
	72.5	2	20.0	Peirson (1995)
	79.2	4	40.0	WA0632
	103.5†, 48*		39.2	WA0720 (full-slat fv)
	80.0†, 70.0†		38.7	WA0720 (fs acnv)
	71.0†, 39*		28.5	WA0720 (part slat)
Fatteners >20kg on straw				
51.6	54.2	2	14.0	Peirson (1995)
	28.3		10.2	Koerkamp *et al.*, 1998
	122.2	4	61.0	WA0632
	24		10.4	AM0102
	47.0		27.2	AM0103 Terrington
	34.1		10.8	AM0103 Commercial
Fatteners <20kg on slats				
27.7	34.8		14.0	Peirson (1995)
	20.6		15.6	Koerkamp *et al.*, 1998
Fatteners <20kg on straw				
19.9				Based on ratio for fatteners >20kg

†From measurements on commercial farms
*From experimental studies at ADAS Terrington

Derivation of NARSES EF: weighted means of 25, 13, 19, 33.2 and 14.8 %TAN for dry sows on straw, dry sows, farrowing, finishing pigs and weaners on slurry, respectively. However, because of the large variation and subsequent uncertainty in measurements of emissions from finishing pigs on straw, the reverse engineered estimate of 22.4% TAN is used for finishing pigs on straw.

Hard standings

UKAEI
An emission factor of 0.32 g NH_3-N animal^{-1} d^{-1} for pig loading areas (Misselbrook *et al.*, 2001).

NARSES EF derived as 75% of TAN estimated to be deposited by finished pigs as they await loading for dispatch to market (with scraping efficiency assumed to be 30%). 5% of daily excretal output is assumed to be deposited to the loading areas.

Storage

Mean EF g N m^{-2} d^{-1}	Values g N m^{-2} d^{-1}	Derived from n values	Emission as %TAN	Source
Slurry stores and lagoons				
3.16	1.34	4	13.0	*WA0632
	2.47, 6.2		NA	WA0625
	2.4		NA	Phillips *et al*. (1997)
	1.56		NA	WA0708
	5.0		NA	Phillips et al., in press
FYM heaps	**g N t^{-1} initial heap mass**			
1224	539	4	20.0	*WA0632
	1015	1	68.0	WA0716

UKAEI
Values derived from measurements made using Ferm tubes have been corrected to account for incomplete recovery of ammonia by Ferm tubes (Phillips *et al*., 1998).

As for cattle slurry, a common EF is used for circular tanks and lagoons.

Emissions from FYM stores were previously based on surface area. However, it was considered that the estimates of store surface areas (Nicholson and Brewer survey, 1994) seriously underestimated solid manure storage areas (possibly because of multiple use of the same area or not accounting for short-term storage heaps). Therefore emissions are now calculated on a per tonne basis (using data from the same experimental studies).

NARSES
NARSES EF for slurry tanks was derived as 13 %TAN and for lagoons the same values as for cattle slurry lagoons (52 %TAN) was used. The weighted mean of measurements made during storage of FYM is 30% of TAN, similar to that for emissions during storage of cattle FYM.

POULTRY

Outdoors

NARSES – a lower EF of 35 %UAN has been applied, as it is likely that emissions from freshly dropped excreta will be substantially lower than from applications of stored manure in which hydrolysis of the uric acid will have occurred to a greater extent. 20% of poultry droppings are estimated to be voided outside the house (Pers. comm. Elson, ADAS); this is an increase on the previous estimate of 12%, and represents a real change in that newer systems are designed such that birds do spend longer outside.

Land spreading

For poultry manure a standard EF of 52.3 %UAN applied is used, with no further modifiers for soil, manure or weather (KT0106, MANNER_PSM)

For Duck manure, which is very similar to cattle/pig FYM, an EF of 68.3 %UAN applied is used.

Abatement – incorporation
Incorporation within 4h gives 85% reduction
Incorporation within 24h gives 55% reduction
Values derived from using MANNER_PSM (Project KT0106), assuming incorporation by plough.

Housing

Mean EF gN $lu^{-1}d^{-1}$	Values gN $lu^{-1}d^{-1}$	Derived from n values	Emission as %TAN	Source
Layers – deep-pit (cages, perchery, free-range)				
149	146		35.9	Groot Koerkamp *et al*., 1998 (perchery)
	184		45.2	Groot Koerkamp *et al*., 1997 (deep-pit)
	79	3	18.0	Peirson (1995) (deep-pit)
	139		33.1	WA0368 (deep-pit)
	197	6	46.8	WA0651 (belt-scraped, Bitteswell)
Layers – belt-cleaned (cages)				
60	36	3	4.0	Peirson (1995)
	79	6	23.9	WA0651 (weekly scraping)
	65	7	15.4	WA0651 (belt scraped, Bitteswell)
Broilers/all other poultry				
64	79		14.7	Demmers et al (1999)
	92	3	46.0	Peirson (1995, turkeys)
	44	4	4.8	Robertson et al. (2002)
	36	4	10.7	WA0651 (winter)
	67	2	10.3	WA0651 (summer)
	53	2	10.8	WA0651 (drinker study)

NARSES EF was derived as 37.4 %UAN for buildings housing laying hens in deep-pit or perchery systems and 16.5% belt cleaning (a reduction of 56%). For broilers the weighted mean is 8.1 %UAN.

Layers in cages – systems where manure is scraped from a collection shelf through a floor slot to a deep-pit are included in the cages deep-pit category. Measurements under WA0651 indicated that a much lower emission factor was obtained for a daily belt-cleaning system as compared with weekly cleaning. However, such frequent cleaning would not be practised on commercial farms and the value is therefore not included here.

A measurement from Groot Koerkamp *et al*. (1998) for broiler housing (164 g N lu^{-1} d^{-1}) has been excluded from the inventory. This measurement was from an old housing system, no longer representative of current broiler housing, and was also based on a single measurement in time rather than an integrated measurement over the duration of the crop.

Storage

Storage losses can be divided into storage and 'break-out' (*i.e.* when loading to trailer/spreader takes place).

Storage losses

Mean EF **g N t^{-1} initial heap mass**	Values	Derived from n values	Emission as %TAN	Source
Layer manure				
1956	318	2	2.2	WA0712
	3172	4	15.1	WA0651 (belt scraped)
	3141	4	29.4	WA0651 (deep pit)
	1193	1	13.4	WA0651 (belt scraped)
Litter				
1435	478	1	2.2	WA0712
	1949	4	19.9	WA0651 (winter)
	158	4	2.0	WA0651 (summer)
	639	2	7.2	WA0651 (drinkers)
	3949		NA	WA0716

UKAEI
Emissions from FYM stores were previously based on surface area. However, it was considered that the estimates of store surface areas (Nicholson and Brewer survey, 1994) seriously underestimated solid manure storage areas (possibly because of multiple use of the same area or not accounting for short-term storage heaps). Therefore emissions are now calculated on a per tonne basis (using data from the same experimental studies).

NARSES
NARSES EF were derived from weighted means as 17.8 %UAN for layer manure and 8.7% for poultry litter. Duck manure was assumed to have the same EF during storage as cattle FYM (35%).

DEER

Grazing
- Sheep grazing (lowland sheep) emission factor used as liveweights similar.

Land spreading
- Emission factor for cattle FYM used.

Housing
- Emission factor for sheep housing used.

Storage
- Emission factor for cattle FYM used.

HORSES

Mean EF of 10.6 kg NH_3-N per animal per year used, as for ‘other horses’ in non-agricultural emissions inventory (Sutton *et al*., 2000).

NARSES EF derived using reverse-engineering as 35 %TAN, based on the UKAEI EF.

CONSERVED GRASSLAND & TILLAGE

NARSES
A model based on Misselbrook et al. (2004) but modified according to data from the NT26 project is used to estimate EF for different fertiliser types:

- Ammonium nitrate (and ‘other N’ category) – a fixed emission factor of 1.8% N applied is now used as there was no consistent evidence of temperature, rainfall, land-use or crop height effects on emission. The only modifier applied is for direct placement of fertiliser into soil on tillage, where a reduction efficiency of 80% is assumed.
- Ammonium sulphate, diammonium phosphate – for this minor category of fertilisers, soil pH has an influence on emissions. The rules for ammonium nitrate are applied for applications to non-calcareous soils and the rules for urea are applied for applications to calcareous soils.
- Urea ammonium nitrate – a maximum EF of 23% is applied (from NT26 data-set) and the rules for urea applications are applied.
- Urea – EF is derived according to EF_{max}, application rate, rainfall and temperature. EF_{max}, is 45% (from NT26 data-set). The modifiers for application rate, rainfall and temperature were revised to be consistent with the NT26 model.
- 10% of fertiliser applied to tillage is assumed to be by soil placement
- Mean application rate of urea for a given application timing is assumed to be 60 kg ha^{-1} N (previously 120)

Sources of Activity Data

Animal numbers and weights

Livestock numbers are obtained from census statistics provided by each devolved administration (England, Scotland, Wales and Northern Ireland). The UK total is derived as the sum of the DA values.

Livestock weights (required in UKAEI but not NARSES) are from ADAS unpublished data:

Animal	Weight (kg)
Dairy cow (inc. heifers)	550
Dairy heifer in calf	400
Beef cow (inc. heifers)	
Beef heifer in calf	
Bull	340
Others > 2 yr	
Others 1-2 yr	
Others < 1yr	140

Animal	Weight (kg)
Sow	200
Farrower	225
Boar	250
Fattener >110 kg	120
Fattener 20 – 110 kg	65
Fattener <20 kg	12
Layer	2.2
Broiler	0.9
Pullet	1.0
Breeding hen	2.0
All other poultry	4.0

Proportion of sheep in uplands from ADAS (Diane Spence).

Excretal outputs and TAN contents

Manure output values per animal are from Smith and Frost (2000) and Smith *et al*., (2000). Account is taken of time spent indoors and litter/bedding is included for FYM outputs. For milking dairy cattle, time indoors is increased to account for time in summer spent in buildings or yards for milking operation (equivalent to 3h per day throughout the grazing period). N excretion values are derived from Cottrill, B.R. and Smith,K.A. (2007) 'Nitrogen output of livestock excreta', Final report, Defra Project WT0715NVZ, June 2007. Manure TAN contents from expert opinion.

Proportion of waste produced as slurry or FYM from ADAS Surveys of Animal Manure Practices in the Dairy, Beef, Pig and Poultry Industries (Smith *et al*., 2000c, 2001a, 2001b).

Slurry TAN contents from Smith and Frost (2000) and Smith *et al*., (2000a) with 50 % of total N assumed to be ammoniacal-N. TAN contents of FYM assumed to be 10 % of total N for stored FYM and 25 % for FYM spread to land directly from the house, obtained from MAFF (2000), Tables 1 & 2. Poultry AUN contents from MAFF (2000).

Tonnage of poultry litter incinerated obtained directly from EPRL and Fibropower websites (K Smith, ADAS).

Manure output and N excretion by livestock category (2008 values)

Livestock type	Manure output kg d^{-1}		% manure produced as …		N excretion kg yr^{-1}	%TAN at excretion
	Slurry	FYM	Slurry	FYM		
Cattle						
Dairy cows & heifers	52.7	68.5	66	34	118.4	60
Dairy heifers in calf	31.9	41.5	66	34	67	60
Dairy replacements >2 yrs	31.9	41.5	18	82	56	60
Dairy replacements 1-2 yrs	25.8	33.5	18	82	56	60
Dairy bulls > 2 yrs	31.9	41.5	18	82	53	60
Dairy bulls 1-2 yrs	25.8	33.5	18	82	56	60
Dairy calves	14.5	18.9	0	100	38	60
Beef cows & heifers	31.9	41.5	18	82	79	60
Beef heifers in calf	25.8	33.5	18	82	56	60
Bulls >2 yrs	31.9	41.5	18	82	53	60
Bulls 1-2 yrs	25.8	33.5	18	82	56	60
Beef > 2 yrs	31.9	41.5	18	82	56	60
Beef 1-2 yrs	25.8	33.5	18	82	56	60
Beef calves	14.5	18.9	0	100	38	60
Sheep						
Ewes - lowland		5.3	0	100	10.5	60
Ewes - upland		5.3	0	100	9.9	60
Lambs - lowland		2.6	0	100	0.6	60
Lambs - upland		2.6	0	100	0.7	60
Goats					20.6	60
Deer					13	60
Pigs						
Maiden gilts	10.9	13.6	35	65	15.5	70
Sows			35	65	18.9	70
Boars	10.9	13.6	0	100	22.9	70
Fatteners >110 kg			33	67	16.1	70
Fatteners 80-110 kg			33	67	16.1	70
Fatteners 50-80 kg			33	67	13.9	70
Fatteners 20-50 kg			33	67	9.3	70
Weaners (<20 kg)	1.3	1.4	53	47	3.6	70
Poultry						
Laying hens (cages)		0.11	0	100	0.70	70
Laying hens (free-range)		0.11	0	100	0.78	70
Broilers		0.05	0	100	0.44	70
Pullet		0.02	0	100	0.33	70
Breeding Hens		0.11	0	100	1.04	70
Turkeys (m)		0.09	0	100	2.16	70
Turkeys (f)		0.09	0	100	1.44	70
Ducks		0.09	0	100	1.67	70
Horses			0	100	50	60

Manure volume output data derived from Smith et al. (2000c, 2001a, 2001b) with interpretation for animal place and annual outputs by K Smith (ADAS). Nitrogen excretion data from project WT0715NVZ with interpretation by B Cotteril and K Smith (ADAS).

Land spreading

Proportion of pig or cattle manure applied to grassland and arable, proportion applied in summer (May-July), proportion applied by injection or irrigated and proportion incorporated within 1d or 1wk of application obtained from ADAS Surveys of Animal Manure Practices in the Dairy, Beef, Pig and Poultry Industries (Smith *et al*., 2000c, 2001a, 2001b). Proportion of cattle and pig FYM spread to land without storage also obtained from the same source. Proportion of poultry manure applied to grassland and arable obtained from Farm Practices Survey (Defra 2001).

Proportion of slurry in each dry matter category from ADAS unpublished (K Smith, B Chambers).

Housing

Proportion of animals in each housing type - cattle from ADAS Surveys of Animal Manure Practices in the Dairy and Beef Industries (1998), pigs from Sheppard (1998, 2002). Proportion of pigs outdoors from Sheppard (1998, 2002). Poultry housing and % manure dropped outdoors provided by A Elson (ADAS).

Cattle housing periods obtained from ADAS Surveys of Animal Manure Practices in the Dairy and Beef Industries (1998), with housing period of milking dairy cattle extended to account for time in for milking during the summer months. For sheep, ewes indoors for 30 d, lambs not indoors at all. Poultry and pigs assume 100 % occupancy as June census takes a snapshot of animal numbers which will reflect the actual % occupancy.

Storage

Proportions of manure stored in different store categories derived from Farm Practices Surveys.

The proportion of cattle stores crusted estimated from ADAS Surveys of Animal Manure Practices in the Dairy and Beef Industries (1998), with stores stirred never or only occasionally assumed to be crusted.

Hard standings

UKAEI input data

Usage derived from survey conducted under WA0528 (Webb *et al.*, 2001) and from NT2402†.

Hard standing	Area per animal (m^2)	% animals using hard standing	Usage (Days per year)
Dairy cow collecting yard	2.15 (1.74, 2.55†)	65	358 (365, 358†)
Dairy cow feeding/loafing yard	3.03 (1.70, 3.03†)	30	303 (365, 240†)
Dairy cow self-feed silage yard	4.75	14	180
Beef cattle feeding/loafing yard	4.32	45	180
Beef cattle self-feed silage	4.71	9	180
Sheep handling area – lowland sheep	0.92	67	24
- upland sheep	0.92	67	6
Pig loading area	1.00	19	4

NB Area per animal not actually used in calculation, but included here for reference.

Fertiliser

Fertiliser usage in England, Wales and Scotland derived from British Survey of Fertiliser Practice 2008 (http://www.defra.gov.uk/environ/pollute/bsfp/index.htm) and for Northern Ireland from DARDNI stats (http://www.dardni.gov.uk/econs/.htm).

References

Baines, S., Svoboda, I. F. and Sym, G. (1997*) Estimates of slurry, manure storage and housings in use in Scotland and Northern Ireland*. Report to MAFF (WA0620), SAC Ayr.

Bussink, D.W. (1994). Relationship between ammonia volatilization and nitrogen fertilizer application rate, intake and excretion of herbage nitrogen by cattle on grazed swards. *Fertilizer Research* **38**, 111-121

CAMAR: Groot Koerkamp, P. W. G., Metz, J. H. M., Uenk, G. H., Phillips, V. R., Holden, M. R., Sneath, R. W., Short, J. L., White, R. P., Hartung, J., Seedorf, J., Schröder, M., Linkert, K. H., Pedersen, S., Takai, H., Johnsen, J. O. and Wathes, C. M., 1998. Concentrations and emissions of ammonia in livestock buildings in Northern Europe. *Journal of Agricultural Engineering Research* **70**, 79-95.

Chalmers, A. G., et al. (2001). *Fertiliser use on farm crops for crop year 2000*. British Survey of Fertiliser Practice, Edinburgh: The Stationery Office.

Chambers, B.J., Smith, K.A. and van der Weerden, T.J. (1997). Ammonia emissions following the land spreading of solid manures. In *Gaseous Nitrogen Emissions from Grasslands*. Eds S.C. Jarvis and B.F. Pain, CAB International, Oxford, pp. 275-280.

Chambers, B. J., Lord, E. I., Nicholson, F. A. and Smith, K. A. (1999). Predicting nitrogen availability and losses following application of organic manures to arable land: MANNER. Soil Use and Management 15, 137-143.

DANI (1998). Statistical Review of Northern Ireland Agriculture, 1997. Department of Agriculture for Northern Ireland, Economics and Statistics Division, Belfast, Northern Ireland, UK.

Defra (2001) http://www.defra.gov.uk/esg/work_htm/publications/cs/fps/fpsfinalreport.PDF

Demmers, T.G.M., Phillips, V.R., Short, J.L., Burgess, L.R., Hoxer, R.P. and Wathes, C.M (1997). Validation of ventilation rate measurement methods and the ammonia emission from a naturally-ventilated UK dairy and beef unit. In*: Ammonia and Odour Emissions from Animal Production Facilities*. Eds J.A.M. Voermans and G.J. Monteney, Proceedings of an international symposium held at Vinkeloord, Netherlands, 6-10 October 1997. Published by NTVL, Rosmalen, NL pp. 219-230.

Demmers, T.G.M., Burgess, L.R., Short, J.L., Phillips, V.R., Clark, J.A. and Wathes, C.M. (1999). Ammonia emissions from two mechanically ventilated UK livestock buildings. *Atmospheric Environment* **33**, 217-227.

Dore, C. J., Jones, B. M. R., Scholtens, R., Burgess, L. R., Huis in't Veld, J. W. H., Phillips, V. R. (2004). Robust methods for measuring ammonia emission rates from livestock buildings and manure stores. Part 1 Comparative demonstrations of three methods on the farm. *Atmospheric Environment* **38**, 3017-3024.

Hill, R.A. (2000). Emission, dispersion and local deposition of ammonia volatilised from farm buildings and following the application of cattle slurry to grassland. PhD Thesis, University of Plymouth.

Hodge, I. and Renwick, A. (2006). Business as usual projections of agricultural activities for the water framework directive: Phase 2. Final Report. Rural Business Unit, Environmental Economy and Policy Research Group, Department of Land Economy, 19 Silver Street, Cambridge CB3 9EP.

Jarvis, S.C; Hatch, D. J; Orr, R.J. and Reynolds, S.E. (1991). Micrometeorological studies of ammonia emissions from sheep grazed swards. *Journal of Agricultural Science Camb*ridge, **117**, 101-109

Jarvis, S. C. and Bussink, D. W. (1990). Nitrogen losses from grazed swards by ammonia volatilization. Proceedings of the 13th General Meeting of the European Grassland Federation, June 25-29, 1990, Banska Bystrica, Czechoslovakia, p.13-17.

Kirchmann, H., and Witter, E. (1989). Ammonia volatilization during aerobic and anaerobic manure decomposition. *Plant and Soil* **115**, 35-41.

Koerkamp, P., Metz, J. H. M., Uenk, G. H., Phillips, V. R., Holden, M. R., Sneath, R. W., Short, J. L., White, R. P., Hartung, J., Seedorf, J., Schroder, M., Linkert, K. H., Pedersen, S., Takai, H., Johnsen, J. O. and Wathes, C. M. (1998). Concentrations and emissions of ammonia in livestock buildings in Northern Europe. *Journal of Agricultural Engineering Research* **70**, 79-95.

Ledgard, S. F. (1996). Nitrogen inputs and losses from New Zealand dairy farmlets, as affected by nitrogen fertilizer applications: year one. *Plant and Soil* **181**, 65-69.

MAFF (2000). *Fertilizer Recommendations for Agricultural and Horticultural Crops (RB209), 7th Edition*. Her Majest's Stationery Office, London, UK.

Mercer, D. R. (1993*) Estimates of the number and types of poultry housing in use in England and Wales.* Report to MAFF, ADAS Nottingham.

Misselbrook, T.H., Webb, J. and Gilhespy, S.L. (2006). Ammonia emissions from outdoor concrete yards used by livestock – quantification and mitigation. *Atmospheric Environment* **40**, 6752-6763.

Misselbrook, T.H., Sutton, M.A. and Scholefield, D. (2004). A simple process-based model for estimating ammonia emissions from agricultural land after fertilizer applications. *Soil Use and Management* **20**, 365-372.

Misselbrook, T. H., Smith, K. A., Johnson, R. A. and Pain, B. F. (2002). Slurry application techniques to reduce ammonia emissions: Results of some UK field-scale experiments. *Biosystems Engineering* **81**, 313-321.

Misselbrook, T. H., Webb, J., Chadwick, D. R., Ellis, S. and Pain, B. F. (2001). Gaseous emissions from outdoor concrete yards used by livestock. *Atmospheric Environment* **35**, 5331-5338.

Misselbrook, T. H., Pain, B. F. and Headon, D. M. (1998). Estimates of ammonia emission from dairy cow collecting yards. *Journal of Agricultural Engineering Research* **71**, 127-135.

Nicholson, F. A., Chambers, B. J. and Smith, K. A. (1996) Nutrient composition of poultry manures in England and Wales. *Bioresource Technology* **58**, 279-284.

Nicholson, R. J. and Brewer, A. J. (1994) *Estimates of the numbers and types of slurry and manure stores in use in England and Wales related to livestock species*. Report to DEFRA (WA0611), ADAS Cambridge.

Pain, B. F., Rees, Y. J. and Lockyer, D. R. (1988). Odour and ammonia emission following the application of pig or cattle slurry to land. In*: Volatile emissions from livestock farming and sewage operations*, eds V C Neilsen, J H Voorburg and P L'Hermite. Elsevier Applied Science, London, pp. 2 - 11.

Pain, B. F., Phillips, V. R., Clarkson, C. R. and Klarenbeek, J. V. (1989). Loss of nitrogen through ammonia volatilisation following the application of pig or cattle slurry to grassland. *Journal of the Science of Food and Agriculture* **47**, 1-12.

Peirson, S. (1995). Measurement of odour and ammonia emissions from livestock buildings, Phase 1 - Final Report to MAFF. Project no. WAO601, ADAS Beverley.

Phillips, V.R., Sneath, R.W., Williams, A.G., Welch, S.K., Burgess, L.R., Demmers, T.G.M. and Short, J.L. (1997). Measuring emission rates of ammonia, methane and nitrous oxide from full-sized slurry and manure stores. In*: Ammonia and Odour Emissions from Animal Production Facilities*. Eds J.A.M. Voermans and G.J. Monteney, Proceedings of an international symposium held at Vinkeloord, Netherlands, 6-10 October 1997. Published by NTVL, Rosmalen, NL pp. 197-208.

Phillips, V. R., Bishop, S. J., Price, J. S. and You, S. (1998). Summer emissions of ammonia from a slurry-based, UK, dairy cow house. *Bioresource Technology* **65**, 213-219.

Robertson, A. P., Hoxey, R. P., Demmers, T. G. M., Welch, AS. K., Sneath, R. W., Stacey, K. F., Fothergill, A., Filmer, D. and Fisher, C. (2002). Commercial-scale studies of the effect of broiler-protein intake on aerial pollutant emissions. *Biosystems Engineering* **82**, 217-225.

Sheppard, A. (1998) The Structure of Pig Production in England and Wales. Results of the National Survey of Pig Production Systems. *Special Studies in Agricultural Economics Report No. 40,* University of Exeter.

Smith, K. A. and Chambers, B. J. (1995). Muck from waste to resource - utilization: the impacts and implications. *Agricultural Engineer*, **50**, 33-38.

Smith, K. A. and Frost, J. P. (2000). Nitrogen excretion by farm livestock with respect to land spreading requirements and controlling nitrogen losses to ground and surface waters. Part 1: cattle and sheep. *Bioresource Technology* **71**, 173-181.

Smith, K. A., Charles, D. R. and Moorhouse, D. (2000a). Nitrogen excretion by farm livestock with respect to land spreading requirements and controlling nitrogen losses to ground and surface waters. Part 2: pigs and poultry. *Bioresource Technology* **71**, 183-194.

Smith, K. A., Jackson, D. R., Misselbrook, T. H., Pain, B. F. and Johnson, R. A. (2000b). Reduction of ammonia emission by slurry application techniques. *Journal of Agricultural Engineering Research* **77**, 277-287.

Smith, K. A., Brewer, A. J., Dauven, A. and Wilson, D. W. (2000c). A survey of the production and use of animal manures in England and Wales. I. Pig manure. Soil Use and Management 16, 124-132.

Smith, K. A., Brewer, A. J., Crabb, J. and Dauven, A. (2001a). A survey of the production and use of animal manures in England and Wales. II. Poultry manure. Soil Use and Management 17, 48-56.

Smith, K. A., Brewer, A. J., Crabb, J. and Dauven, A. (2001b). A survey of the production and use of animal manures in England and Wales. III. Cattle manures. Soil Use and Management 17, 77-87.

Sommer, S.G., Christensen, B.T., Nielsen, N.E., and Schjrrring, J.K. (1993). Ammonia volatilization during storage of cattle and pig slurry: effect of surface cover. *Journal of Agricultural Science, Cambridge*, **121**, 63-71.

Sutton, M. A., Dragosits, U., Tang, Y. S. and Fowler, D. (2000). Ammonia emissions from non-agricultural sources in the UK. *Atmospheric Environment* **34**, 855-869.

Thompson, R. B., Pain, B. F. and Lockyer, D. R. (1990a). Ammonia volatilization from cattle slurry following surface application to grassland. I. Influence of mechanical separation, changes in chemical composition during volatilization and the presence of the grass sward, *Plant and Soil* **125**, 109-117.

Thompson, R. B., Pain, B. F. and Rees, Y. J. (1990b). Ammonia volatilization from cattle slurry following surface application to grassland. II. Influence of application rate, windspeed and applying slurry in narrow bands. *Plant and Soil* **125**, 119-128.

van der Weerden, T. J. and Jarvis, S. C. (1997). Ammonia emission factors for N fertilisers applied to two contrasting grassland soils. *Environmental Pollution* **95**, 205-211.

Wathes, C. M., Holden, M. R., Sneath, R. W., White, R. P. and Phillips, V. R. (1997). Concentrations and emission rates of ammonia, nitrous oxide, methane, carbon dioxide, dust and endotoxin in UK broiler and layer houses. *British Poultry Science* **38**, 14-28.

Webb, J., (2001). Estimating the potential for ammonia emissions from livestock excreta and manures. *Environmental Pollution* **111**, 395-406.

Webb, J., and Misselbrook, T. H. (2004). A mass-flow model of ammonia emissions from UK livestock production. *Atmospheric Environment* **38**, 2163-2176.

Webb, J., Misselbrook, T., Pain, B. F., Crabb, J. and Ellis, S. (2001). An estimate of the contribution of outdoor concrete yards used by livestock to the UK inventories of ammonia, nitrous oxide and methane. *Atmospheric Environment* **35**, 6447-6451.

Welch, D.C. (2003) A methodology for the measurement of distributed agricultural sources of ammonia outdoors. PhD thesis, University of Nottingham.

Williams, J. R., Chambers, B. J., Hartley, A. R., Ellis, S. and Guise, H. J. (2000). Nitrogen losses from outdoor pig farming systems. *Soil Use and Management* **16**, 237-243.

DEFRA Projects

Final reports from the following projects are available from DEFRA

AM0101	National ammonia reduction strategy evaluation system (NARSES)
AM0102	Modelling and measurement of ammonia emissions from ammonia mitigation pilot farms
AM0103	Evaluation of targeted or additional straw use as a means of reducing ammonia emissions from buildings for housing pigs and cattle
AM0110	Additional housing measurements for solid vs. liquid manure management systems
AM0111	Measurement and abatement of ammonia emissions from hard standings used by livestock
AM0115	Investigation of how ammonia emissions from buildings housing cattle vary with the time cattle spend inside them
KT0106	MANNER - Policy Support Model (MANNER-PSM)
LK0643	UK Poultry Industry IPPC Compliance (UPIC)
NT2001	Integration of animal manures in crop and livestock farming systems: nutrient demonstration farms
NT2402	Impact of nutrition and management on N and P excretions by dairy cows
NT2605	The behaviour of some different fertiliser-N materials - Main experiments

OC9117	Ammonia emission and deposition from livestock production systems
WA0519	Enhancing the effective utilisation of animal manures on-farm through effective compost technology
WA0618	Emissions from farm yard manure based systems for cattle
WA0625	The effects of covering slurry stores on emissions of ammonia, methane and nitrous oxide
WA0632	Ammonia fluxes within solid and liquid manure management systems
WA0633	Predicting ammonia loss following the application of organic manures to land
WA0638	Low cost, aerobic stabilisation of poultry layer manure
WA0641	Low-cost covers to abate gaseous emissions from slurry stores
WA0651	Ammonia fluxes within broiler litter and layer manure management systems
WA0652	Field ammonia losses in sustainable livestock LINK Project LK0613
WA0653	Quantifying the contribution of ammonia loss from housed dairy cows to total N losses from dairy systems (MIDaS2)
WA0707	Effect of storage conditions on FYM composition, gaseous emissions and nutrient leaching during storage
WA0708	Covering a farm scale lagoon of pig slurry
WA0712	Management techniques to minimise ammonia emissions during storage and land spreading of poultry manures
WA0714	Natural crusting of slurry storage as an abatement measure for ammonia emission on dairy farms
WA0716	Management techniques to reduce ammonia emissions from solid manures
WA0717	Ammonia emissions and nutrient balance in weeping-wall stores and earth banked lagoons for cattle slurry storage
WA0720	Demonstrating opportunities of reducing ammonia emissions from pig housing
WA0722	Ammonia emission from housed dairy cows in relation to housing system and level of production
WT0715NVZ	Nitrogen and phosphorus output standards for farm livestock