MINISTRY OF AGRICULTURE, FISHERIES AND FOOD **CSG 15**

Research and Development

Final Project Report

(Not to be used for LINK projects)

Two hard copies of this form should be returned to:
Research Policy and International Division, Final Reports Unit
MAFF, Area 6/01
1A Page Street, London SW1P 4PQ
An electronic version should be e-mailed to c.csgfinrep@csg.maff.gsi.gov.uk

Project title	Additional measurements of ammonia from beef cattle housed in straw- and slurry-based housing systems		
MAFF project code	**AM0110**		
Contractor organisation and location	IGER North Wyke, Okehampton, Devon, EX20 2SB.		
Total MAFF project costs	£ 30,307		
Project start date	23/10/00	Project end date	01/06/01

Executive summary (maximum 2 sides A4)

This project was initiated as a follow-on from MAFF-funded project WA0632 which was designed to provide additional data for use in the UK ammonia emission inventory and to determine if a move from slurry- to straw-based systems could significantly reduce ammonia emissions through the entire management continuum as well as having the added benefit of increased animal welfare. Cattle are the largest contributors of all the livestock classes to the annual ammonia emission, accounting for 56% (137 kt NH_3-N yr^{-1}) of the total emission from UK agriculture (data from recent UK ammonia emission inventory update project, AM0108). Furthermore, losses from cattle housing account for 30% of the total emission from cattle farming. Within the housing component of the inventory, ammonia losses from straw (solid)- and liquid (slurry)-based manure systems were initially assumed to be the same as there was no comparative information at the time. As 34% of dairy cattle and 82% of beef cattle are on straw-based systems, any differences in emission factors for the two types of system could have a profound influence on the total.

Work carried out under project WA0632 determined that ammonia emissions from cattle housed on liquid management systems were greater than emissions on solid management systems. However, there was a large variation in emission from the two management systems over the two winter housing periods with emission during year 2 being 40% greater than year 1. The third year of measurements under this project were made to provide additional information with which to generate a robust emission factor for use in the UK ammonia inventory.

The overall objective of the study was to quantify and compare ammonia emission from cattle housed in slurry and straw based systems. In detail, the specific objectives were:-

? To quantify feed N intake over the housing period

? To quantify N excreted by cattle during the housing period

? To measure ammonia emission from cattle housed in solid and liquid based systems, and,

? To compare emission factors from beef cattle in slurry and straw based systems with those measured in WA0632.

The same methodology was used in this project as in WA0632. Four beef cattle were penned in specially adapted polytunnel houses of which two were modified to simulate slurry-based systems and two to simulate straw-based systems. Cattle were fed a diet of grass silage *ad libitum* and rolled barley and either bedded with straw or the slurry scraped daily. Ammonia emissions were measured twice each week for periods of at least 2-3 hours, both prior to and following the daily addition of straw and slurry scraping. The manure that built up in the solid system was removed twice during the winter housing period, so the measurements made during the housing phase were split into 'period 1' and 'period 2' coinciding with the build up and subsequent removal of the FYM.

Unfortunately, due to the foot and mouth disease outbreak, experimental measurements were curtailed from 22nd February 2001. Therefore, an N budget for period 1 of the housing phase, which ran from 31st October 2000 - 31st January 2001 (92 days), was constructed. Resources were then re-allocated into carrying out a detailed inter-year comparison between housing measurements made under project AM0110 with those under WA0632. The main findings were as follows:-

? The feed N intake on both the solid and liquid systems was 208 g lu^{-1} d^{-1}, this being much lower than during project WA0632.

? N output in the manure was much lower during AM0110 than WA0632 with a mean of 17.2 kg of N (75 g N lu^{-1} d^{-1}) removed from the liquid system and 30.0 kg of N (133 g N lu^{-1} d^{-1}) from the solid system.

? Ammonia-N losses from the solid manure system were lower (19.1 g lu^{-1} d^{-1}) than from the liquid manure system (28.7 g lu^{-1} d^{-1}) during period 1 of the housing period.

? The rate of ammonia-N loss was reduced from 0.9 to 0.7 g lu^{-1} hr^{-1} following the daily addition of straw.

? Ammonia-N losses from both the solid and liquid systems were *c.* 50% and 40% of those measured during WA0632 year's 1 and 2, respectively.

? A lower proportion of the feed N intake was lost as ammonia-N during this project (*c.* 10%) than during WA0632.

? A common emission unit was calculated for period 1 of the housing periods of WA0632 and AM0110: a mean of 0.2 and 0.3 kg NH_3-N was emitted per kg N excreted on the solid and liquid systems, respectively.

? Emission factors measured under WA0632 were higher than the inventory figures whereas those measured under AM0110 were lower.

In summary, during this project animal N intake was comparatively lower than during project WA0632 due to a lower N content in the silage. The low N intakes by the cattle resulted in low N excretion rates and consequently low ammonia emission. As well as directly reducing the available pool of N subject to volatilisation, low feed N contents are associated with poor digestibility, which may indirectly reduce ammonia volatilisation.

Despite the variations in silage quality and thus N intake across the three years, a common emission unit was calculated on the solid and liquid management systems throughout all housing years. A consistent loss of 0.2 and 0.3 kg NH_3-N per kg N excreted was calculated for the solid and liquid systems, respectively. This suggests that it may be possible to predict ammonia emission from N excretion. The total N excreted was estimated from that removed from the building in FYM or slurry plus the quantity of NH_3-N volatilised. This project has highlighted the need for detailed quantitative and qualitative information on dietary N intake and its subsequent assimilation by livestock. This information needs to be coupled with measurements of N excretion and ammonia emissions for modelling purposes.

The effect of straw addition on mitigating ammonia emissions has been observed both during WA0632 and AM0110 and provides an opportunity to abate ammonia emission. This avenue is being explored under project AM0103 where the effects of additional or targeted straw usage on ammonia emissions from housed livestock will be studied.

Scientific report (maximum 20 sides A4)

1. INTRODUCTION

The UK inventory of ammonia (NH_3) emissions has recently estimated that losses from agriculture amount to 245 kt NH_3-N per year (data from project AM0108). The inventory was compiled using UK data from recent MAFF-funded projects studying losses from individual components of the manure management cycles for different livestock groups, and additionally from cattle grazing, sheep production and fertiliser use. Of all the livestock classes, cattle are the largest contributors accounting for 56% (137 kt NH_3-N yr^{-1}) of the total yearly emission. Within the housing component of the inventory, ammonia losses from solid and liquid manure systems were initially assumed to be the same as there was no comparative information at the time of construction. As 34% of dairy cattle and 82% of beef cattle are on FYM systems, any differences in emission factors for the two types of system could have a profound influence on the total.

Recent updates of the inventory have introduced separate emission factors for housed cattle on straw and slurry systems (projects WA0630, AM0108) but these have been generated from a limited number of measurements. WA0632 was designed to provide additional data for use in the inventory and to determine if a move from slurry- to straw-based systems could significantly reduce ammonia emissions through the entire management continuum as well as having the added benefit of increased animal welfare. Work carried out under WA0632 determined that ammonia emissions from animal houses represent approximately 70% of the total losses from the manure management continuum for beef cattle. Furthermore, emissions from cattle housed on liquid management systems were found to be significantly (~45%) greater than those on solid management systems. However, there was a large variation in emission from the two management systems over the two winter housing periods. Losses were approximately 40% greater in year 2 compared to year 1. This difference may have been due to variations in the quality of the feed and thus N intake. The third year of housing measurements made under this project (AM0110) were to provide additional information with which to generate robust emission factors for use in the ammonia inventory.

The information resulting from AM0110 has added to that already gathered under project WA0632. It has also complemented the measurements being made in project WA0706, where the manure generated from the overwintering period of cattle (WA0632) was spread to grass and arable farmlets and the NH_3 and N_2O emissions quantified. The information will allow a more complete evaluation of ammonia emissions from solid and liquid manure based systems to be made. This work also supports DEFRA's policy objectives of quantifying and limiting ammonia losses from agricultural systems, and improving the utilisation of nutrients from farm manures. The data will support UK discussions as part of the UNECE Convention of Long-Range Transboundary Air Pollutants and the EU Acidification Strategy.

2. APPROACHES

2.1. ANIMAL HOUSING AND MANAGEMENT

Beef cattle (Charolais ? Friesian yearling heifers), penned in groups of four, were housed from 31st October 2000 to 9th April 2001 (160 days) at the Institute of Grassland and Environmental Research (IGER), North Wyke. The animals were housed in four specially adapted polytunnels (ASTERAKI *et al*, 1997), with a mean internal volume of 204 m^3, constructed on a concrete base measuring 8.25 x 10.00m.

Two tunnels were managed as a solid (straw-based) system and two as a liquid (slurry-based) system. The animals were held in pens measuring 7.05 x 5.35m (37.7m^2) and 5.60 x 4.40m (24.6m^2) on the solid and liquid systems, respectively. Sufficient straw (*c.* 13 kg d^{-1} per tunnel or 3.3 kg $head^{-1}$ d^{-1}) was added to the solid system (on a daily basis Monday to Friday) to absorb the excreta and provide a dry bedded area for the cattle. The manure that built up in the solid system was removed twice during the winter housing period: thus, the measurements made during the housing phase were split into 'period 1' and 'period 2' coinciding with the build up and subsequent removal of the FYM. The liquid system was equipped with cubicles and slurry scraping of the feed passage was carried out daily into an adjacent below-ground slurry storage facility. The heifers were fed a diet of grass silage *ad libitum* plus rolled barley.

Foot and mouth disease

The foot and mouth disease outbreak prevented measurements from 22nd February 2001 onwards. The slurry (liquid) systems were converted to straw-based (solid) systems on 21st March 2001 for welfare reasons imposed by foot and mouth disease restrictions. Because experimental measurements were curtailed by the foot and mouth outbreak, resources were re-allocated into carrying out a detailed inter-year comparison between period 1 housing measurements made under project AM0110 with those under WA0632.

The duration of periods 1 and 2 for AM0110 and WA0632 was as follows: -

- WA0632 (Year 1) — Period 1: 19th October 1998 - 21st January 1999 = 94 days
Period 2: 22nd January 1999 – 19th April 1999 = 88 days
- WA0632 (Year 2) — Period 1: 18th October 1999 - 19th January 2000 = 93 days
Period 2: 19th January 2000 – 18th April 2000 = 91 days
- AM0110 — Period 1: 31st October 2000 - 31st January 2001 = 92 days
Period 2: 31st January 2001 – 9th April 2001 = 68 days

i.e., period 1 for all three years ranged from 92-94 days.

2.2. NITROGEN INPUTS

FEED N INTAKE AND ANIMAL LIVEWEIGHT

Sufficient round bale silage was weighed into the tunnels on a weekly basis using pallet scales. Sub-samples of the silage were taken on each feeding occasion and analysed for dry matter (DM) and total N using a Carlo-Erba NA2000 nitrogen and carbon analyser. Refusals were weighed out of the tunnels prior to fresh silage being fed so that the total feed N intake could be calculated. Rolled barley was also fed to the cattle on a daily basis increasing in rations from 0.5 to 2.0 kg $head^{-1}$ d^{-1}. To assess animal performance the liveweight of the animals was measured initially and then at monthly intervals for the duration of the experiment.

2.3 NITROGEN OUTPUTS

NITROGEN EXCRETED

The slurry reception pits were emptied on a fortnightly basis into above-ground galvanised steel slurry tanks (24 m^3 capacity) and on each occasion the volume of excreta was measured and the slurry analysed for DM, pH and total N using Kjeldahl digestion and distillation (BRADSTREET, 1965). Ammonium-N and nitrate-N was extracted in 2M potassium chloride. The bedding material in the straw-based systems was removed from the polytunnels after 92 days. This material was also analysed for DM, pH, total N, ammonium-N and nitrate-N.

AMMONIA LOSSES FROM HOUSED CATTLE

Ammonia measurement methodology and calibrations

The front and rear of each tunnel had roll-up doors and the sides could be rolled up to a height of one metre to provide natural ventilation. When NH_3 emission was being measured, the sides and front door were sealed and an opening of 30cm was left at the bottom of the rear door to allow air to be drawn into the tunnel. Ammonia emission rate from the housed animals was measured using acid traps (containing 0.01M orthophosphoric acid), each connected to a pump system with air flow and gas meters. Air was drawn from the rear of the polytunnel through a fan outlet, situated at the front of the tunnel, at *c.* 8.5 m s^{-1} (measured using a hand-held anemometer during each measurement period). The removal of air at *c.* 8.5 m s^{-1} represents a complete air change in the tunnels every 2.5 minutes thus providing adequate ventilation to the housed animals during measurement periods when the tunnels were sealed.

Acid traps were installed to measure the NH_3-N concentration at both the inlet and the outlet of the polytunnels. At the outlet, air was sub-sampled from a spider sampler situated in the fan housing which was composed of a one metre length of aluminium ducting. A honeycomb section was placed upstream of the spider sampler in order to produce laminar airflow. Measurements were made twice each week for periods of at least 2-3 hours, both prior to and following the daily addition of straw and slurry scraping.

Prior to housing the cattle, NH_3 recovery tests were carried out on the polytunnels. Ammonia gas was released into each tunnel at a rate of 150ml/min for 10 minutes (measured using a NH_3 calibrated flow meter) via a sample line that distributed the NH_3 across the width of the tunnel. The percentage recovery of the NH_3 released was measured using the same methodology as described above to measure NH_3 losses from the housed cattle.

Ammonia losses during the movement of FYM from the housing systems to the field storage heap

At the end of period 1 (31st January 2001) the FYM that had built up in the solid manure systems was transferred to field storage heaps. Prior to removing the FYM, ammonia-N loss measurements were made with the cattle in the tunnels and when they had been turned out. Immediately after this, the simulated movement of FYM from the housing systems to the storage heaps was measured for *c.* one hour before all of the FYM was removed to the storage heaps. Ammonia-N loss was measured using the standard methodology detailed above. On completion of the FYM removal from the polytunnels a final NH_3-N loss measurement was made to assess the contribution of the residue left behind after mucking out.

3. RESULTS AND DISCUSSION

The results from project AM0110 are compared with and discussed alongside those from period 1 of both housing periods of project WA0632.

3.1 NITROGEN INPUTS

FEED N INTAKE

The mean total N intake via silage and barley on the solid and liquid systems during period 1 was similar at 42 and 44 kg per tunnel^{-1}, respectively. Although the DM intake was higher during period 1 of the housing phase of AM0110 than that of WA0632 (year 1), the feed N intake was lower due to a lower nitrogen content in the grass silage (Table 1). The mean N content of the silage varied across the years at 23, 28 and 19 g N kg DM. This equates to 14, 18 and 12 % crude protein (N X 6.25) in the DM which is indicative of an average, excellent and poor quality silage for years 1 and 2 of WA0632 and AM0110, respectively (SOFFE, 1995).

The mean DM content of the silages was 23, 34 and 37% during year's 1 and 2 of WA0632 and AM0110, respectively. TAMMINGA *et al* (1991) found that the rate of protein degradation in silages decreased with increasing dry matter content but increased with increasing crude protein (CP) content. Silage fed during project AM0110 had the highest DM% and the lowest CP content therefore according to TAMMINGA *et al* (1991) would have had the lowest protein degradation rate. The silage fed during year 2 of WA0632 also had a high DM% but the high CP content probably compensated this. Further chemical analyses of the feed would have proved useful in explaining interactions between animal liveweight gain, N excretion and ammonia losses.

Table 1. Mean feed intake by the cattle during period 1 of WA0632 and AM0110.

	Silage consumption (kg DM head^{-1})	Silage N intake (kg head^{-1})	Supplement N intake (kg N head^{-1})	Total N intake (kg N head^{-1})
WA0632 Yr 1				
(94 days)				
Solid	389	8.9	2.3	11.2
Liquid	405	9.3	2.3	11.6
WA0632 Yr 2				
(93 days)				
Solid	481	13.6	1.8	15.4
Liquid	515	14.5	1.8	16.3
AM0110				
(92 days)				
Solid	421	8.3	2.3	10.6
Liquid	449	8.6	2.3	10.9

The N intake via supplements was identical during periods 1 of AM0110 and WA0632 (year 1) at 2.3 kg N head^{-1}, being lowest during period 1 of WA0632 (year 2) at 1.8 kg N head^{-1}. The total feed N and DM intake during year 2 of WA0632 was greater than during all other housing periods. Silage intakes were consistently lower for the solid system than the liquid system possibly because the cattle utilised straw as part of their diet and/or because the liquid management system was less favourable in terms of animal welfare and temperature, i.e. cattle may have required greater silage intake for maintenance in the slurry-based systems.

The total N input, including straw, during all years was higher on the solid system (52 kg per tunnel^{-1} during period 1 of AM0110). Mean total straw input into the solid system during period 1 was 1.2 t with a corresponding N input of 10 kg. This figure is within the range of 508-1016 kg straw per animal per 180 days quoted by ADAS/MAFF for beef cattle in a loose housing system (ADAS/MAFF, 1985). Although the quantities of straw varied across the years, in the range 2.4t (based on AM0110 period 1 only) to 3.3t 180 d^{-1}; the N inputs were similar during the three winter housing periods indicating varying N contents of the straw.

ANIMAL LIVEWEIGHT

Mean cattle liveweight gain (LWG) during period 1 of the housing phase was acceptable during WA0632 but poor during AM0110 (Table 2). The cattle housed during AM0110 had the highest initial liveweight (LW) and thus maybe didn't have the potential to increase their liveweight in line with the cattle of WA0632. However, with the knowledge that the silage quality during AM0110 was poor in comparison to WA0632, the low LWG was more likely to have had a nutritional basis. Most of the N in forage and concentrates is contained in proteins, which have to be digested in order to be retained in the animal. It is known (OLDHAM, 1984) that differing protein inputs can influence animals' performance by changing the overall plane of nutrition, to a large extent this resulting in changes of digestibility and associated intake of ration ingredients. For example, VAN VUUREN *et al* (1992) found that when grass fertilised at low N rates (275 kg N ha yr^{-1}) was fed to dairy cows, the digestibilities of organic matter and crude protein were lower than when high N (500 kg N ha yr^{-1}) grass was fed.

TAMMINGA (1991) suggests that a dietary N content of 24 g kg DM or even less may reduce the digestion of other dietary ingredients. Given that the N content of the silage during AM0110 was 19 g N kg DM and including the barley supplement was 22 g N kg DM, it is perhaps not surprising that the animals' performance suffered. Total mean liveweight gain at the end of period 1 was higher for the liquid system than the solid system for all housing periods, probably a reflection of the higher feed intake on the liquid system.

Table 2. Mean initial LW and LWG per tunnel^{-1} and LWG hd^{-1} d^{-1} during period 1 of WA0632 and AM0110.

	Initial LW (kg)	LWG (kg)	LWG hd^{-1} d^{-1} (kg)

WA0632 Yr 1			
(94 days)			
Solid	895	203	0.54
Liquid	895	213	0.57
WA0632 Yr 2			
(93 days)			
Solid	1008	260	0.70
Liquid	1005	275	0.74
AM0110			
(92 days)			
Solid	1050	108	0.29
Liquid	1052	173	0.47

3.2 NITROGEN OUTPUTS

N EXCRETED

During periods 1 of WA0632 and AM0110, lower N intakes generally resulted in lower N excretion rates (Table 3) and consequently lower NH_3 emission (Table 5). Superfluous N in the diet is excreted in the faeces and urine and it is known that a lower nitrogen intake can in turn reduce N output in the excreta (BUSSINK & OENEMA, 1998; MISSELBROOK *et al*, 1998), thereby potentially lowering NH_3 emissions. This was exemplified by SMITS *et al* (1997) who found that feeding cows 0.1 kg rumen protein surplus (RPS) per day^{-1} compared to 1.0 kg RPS day^{-1} resulted in a 39% lower NH_3 emission.

A mean of 8 m^3 of slurry (17.2 kg of N) was produced from the liquid system during period 1 of AM0110 (Table 3), of this, 5.7 kg was in the form of NH_4^+-N. A trace of nitrate was present. A greater quantity, 30.0 kg of N, was removed in *c.* 8 t FYM from the solid system during the manure clearout at the end of period 1 (Table 3). The difference in the total N output from the two systems may be partly explained by the input of 10 kg N in the form of straw to the solid system. A mean of 4.6 kg of NH_4^+-N was removed from the solid system, and in common with the liquid system, N content in the manure was lower for AM0110 than WA0632.

Table 3. Mean excretal N production from the solid and liquid housing systems during period 1 of WA0632 and AM0110

	Liquid manure volume(m^3) / Solid manure mass (t)	Mean dry matter (%)	Total N (kg)	TAN (kg)	Nitrate-N (kg)	Mean pH
WA0632 Yr 1						
(94 days)						
Solid	7.6	19.1	37.8	6.0	0.0	8.2
Liquid	7.2	5.8	23.8	8.1	0.0	8.1
WA0632 Yr 2						
(93 days)						
Solid	9.0	16.8	54.3	16.4	0.0	8.7
Liquid	6.1	9.3	22.9	9.5	0.0	8.2
AM0110						
(92 days)						
Solid	7.7	20.1	30.0	4.6	0.1	8.4
Liquid	8.2	6.7	17.2	5.7	0.1	7.4

The volume of slurry produced during period 1 of the housing phases was highest during project AM0110. However, when the DM% of the slurry is taken into account the actual DM excreted by the cattle increases in accordance with the DM intake. The N outputs from the housing phase during AM0110 were the lowest of all years, this again a reflection of the N intake by the cattle. The volume of slurry collected in the reception pits during WA0632 year 1 was increased due to problems with water leaks into the reception pits.

AMMONIA LOSSES FROM HOUSED CATTLE

An average of 79% of the NH_3 released into the polytunnels during the calibration tests for project AM0110 was recovered (Table 4). One-sample t-tests showed that the mean NH_3 recovery for each tunnel was significantly different from 100%, therefore, the individual recovery factor for each tunnel was applied to all NH_3 emission data measured using the polytunnels.

Table 4. NH_3-N recovered

	% NH_3-N recovered
Tunnel 1	72.6
Tunnel 2	87.9
Tunnel 3	78.6
Tunnel 4	75.1
Mean	78.6

Losses of NH_3-N during this project were 3.9 and 5.9 kg per tunnel^{-1} from the solid and liquid systems, respectively. Ammonia emissions during housing can be expressed in many ways to serve different purposes. Table 5 summarises housing losses of ammonia from years 1 and 2 of WA0632 and AM0110 in different units. The calculations used to derive these expressions are shown below.

Calculations used to derive units presented in Table 5:-

? kg NH_3-N 500kg LWG^{-1} = (kg NH_3-N tunnel^{-1} ? kg LWG tunnel^{-1}) ? 500 kg

? kg NH_3-N LU^{-1} = (kg NH_3-N tunnel^{-1} ? LW tunnel^{-1}) ? 500 kg
i.e. a livestock unit (LU) is standardised to 500kg.

? kg NH_3-N. kg N excreted^{-1}= kg NH_3-N tunnel^{-1} ? (estimate of total N excreted* per tunnel^{-1})
*Derived from total N content of manure (minus straw N input) plus NH_3-N loss.

? kg NH_3-N. kg TAN excreted^{-1}= kg NH_3-N tunnel^{-1} ? (estimate of TAN excreted^{+} per tunnel^{-1})
$^{+}$Derived from TAN content of manure plus NH_3-N loss.

? kg NH_3-N m^{-2} = (kg NH_3-N tunnel^{-1} ? area of pen)

Solid system pen area = 7.05m ? 5.35m = 37.7 m^2
Liquid system pen area = 5.60m ? 4.40m = 24.6 m^2

Ammonia losses measured during AM0110 were much lower than those measured during year 2 of WA0632 regardless of how the results are expressed. The losses when expressed in kg NH_3-N 500kg LWG^{-1} were similar to the loss per tunnel for both years of WA0632 because the LWG of the cattle during these winter housing periods was approximately 500 kg. However, the LWG of the cattle during AM0110 winter housing period was lower and thus when the results are expressed in kg NH_3-N 500kg LWG^{-1}, the loss was comparatively higher.

Table 5. Mean ammonia loss during period 1 of the housing phase of WA0632 and AM0110.

	kg NH_3-N tunnel^{-1}	kg NH_3-N 500kg LWG^{-1}	kg NH_3-N lu^{-1}	kg NH_3-N. kg N excreted^{-1}	kg NH_3-N. kg TAN excreted^{-1}	g NH_3-N head^{-1} d^{-1}	g NH_3-N m^{-2}
WA0632 Yr 1 (94 days)							
Solid	7.6	7.3	3.9	0.2	0.6	20.2	202
Liquid	10.2	9.7	5.1	0.3	0.6	27.1	415
WA0632 Yr 2 (93 days)							
Solid	10.9	10.2	4.8	0.2	0.4	29.3	289
Liquid	14.9	13.7	6.7	0.3	0.5	40.1	606
AM0110 (92 days)							
Solid	3.9	5.7	1.8	0.2	0.5	10.6	103
Liquid	5.9	7.8	2.6	0.3	0.5	16.0	240

In order to put these results into context it is necessary to compare the stocking densities used in this project with those recommended for commercial agriculture. The stocking densities used in WA0632 and AM0110 were 9 m^2/head and 6 m^2/head on the solid and liquid systems respectively. RSPCA guidelines (2000) suggest a minimum lying area of 3.5 m^2/head plus a minimum additional 20% of the bedded area as a non-bedded/loafing area for the solid system. For the liquid system, a lying area (cubicles) plus a minimum additional 50% of the bedded area as a non-bedded/loafing area is recommended. This equates to a minimum of 4.2 m^2/head on the solid system and 5.3 m^2/head on the liquid system. These figures are based on animals of 251-350 liveweight. Hence, the ammonia-N emissions measured during WA0632 and AM0110, particularly on the solid system, may be slightly misrepresentative of commercial practice.

Another factor that may have resulted in lower ammonia emission during AM0110 is that the mean temperatures during period 1 of the housing period were slightly lower during AM0110:-

WA0632 Year 1 8.1 ^oC
WA0632 Year2 8.3 ^oC
AM0110 7.3 ^oC

A common emission unit that was calculated for both the solid and liquid systems and was replicated across the years is kg NH_3-N. kg N excreted^{-1}, and to a lesser extent, kg NH_3-N. kg TAN excreted^{-1}. This may provide an opportunity to predict NH_3-N emission from N excretion. The relationship for kg NH_3-N. kg TAN excreted^{-1} may be less reliable because the TAN excreted was estimated from the FYM TAN content of which the contribution via mineralisation is unknown.

Ammonia losses prior to and following straw addition or slurry scraping

The rate of NH_3 loss measured under project AM0110 prior to and following straw addition and slurry scraping is … nd slurry scraping was 1 … 1.6 and 2.4 g NH_3-N tu … rence in emission rate p … rates of the solid and li … project WA0632. It is th … ucing NH_3-N emission is …

F … scraping.

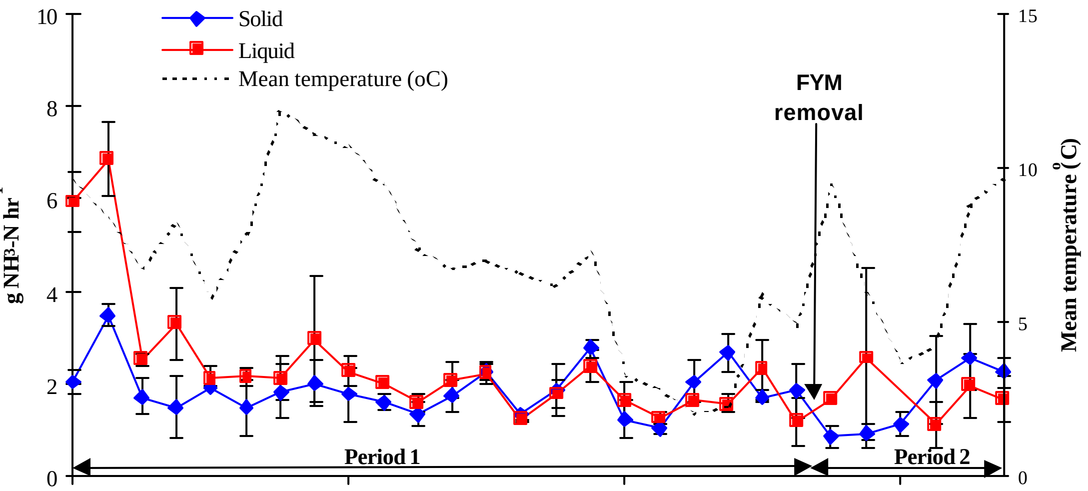
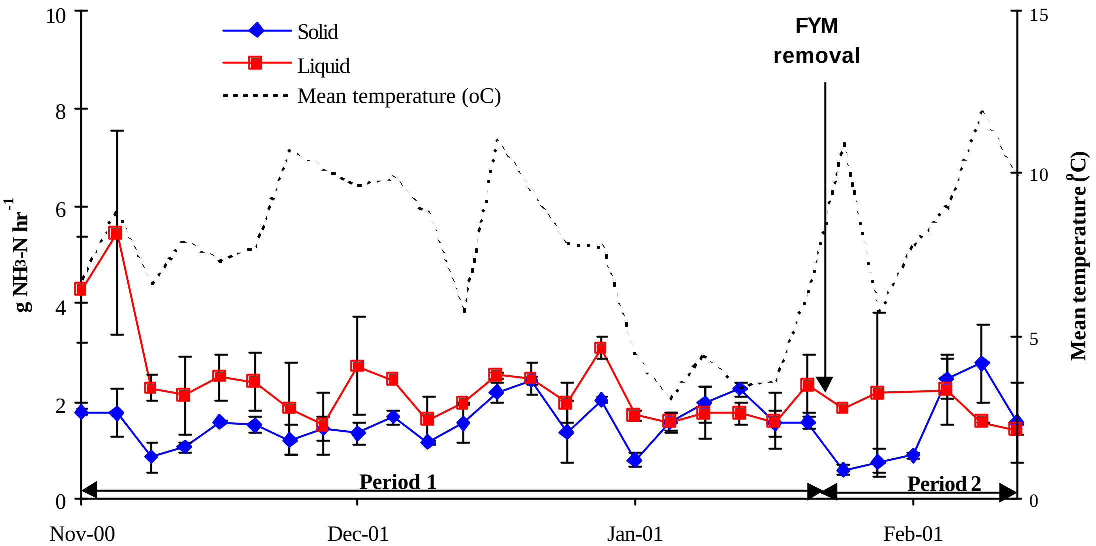


Figure 1b). Mean rate of NH_3 loss per tunnel^{-1} following straw addition or slurry scraping.



The NH_3-N loss on the solid system was reduced following the daily addition of straw with 2.1 kg lost per tunnel^{-1} prior to straw addition and 1.8 kg lost after straw addition, this was also observed in WA0632. Ammonia loss was calculated based on the results from 24 hour monitoring periods during WA0632. Daily ammonia loss was calculated by interpolating measurements made prior to and following straw addition to 12 hours either side of the event. Similarly, ammonia losses measured prior to and following slurry scraping were interpolated to 11 hours 20 minutes either side of the event with the high, but short-lived, emission produced during the act of slurry scraping itself accounting for a 20 minute period. No change in emission was seen following scraping probably as a result of leaving a smear of slurry on the surface of the concrete after scraping. Losses of NH_3 from both the solid and liquid systems were not significantly related to tunnel air temperature (Figures 1a and b).

Ammonia loss as a percentage of the feed N intake

In comparison to measurements made during period 1 of project WA0632, losses of NH_3 were comparatively low during AM0110. Furthermore, the NH_3 loss during the housing phase, as a percentage of the N intake, was much lower during AM0110 (Table 6) than WA0632 (these figures assume that there was no additional N intake via straw).

It is possible that during this project the cattle were not able to retain such a large proportion of the feed N intake due to poor quality silage. If protein in the feed was not digested as a result of poor quality, the undigested feed N would have been excreted with the faeces (BUSSINK & OENEMA, 1998) and although a potential source for volatilisation, is a less immediate threat than N in urine. Urea in urine, which contributes around 70% of the total N (GROOT KOERKAMP *et al* 1998; BRISTOW *et al*, 1992; WHITEHEAD & RAISTRICK, 1993) is readily hydrolysed to produce NH_4^+, and therefore provides the greatest source of ammonia volatilisation. Faeces, conversely, contains low amounts of rapidly decomposable N with only a few per cent of the fresh N in faeces being NH_4^+-N or urea (WHITEHEAD & RAISTRICK, 1993). The major part of the N in faeces is organically bound and up to 50% of this N may become mineralised during storage for 6 months (WHITEHEAD & RAISTRICK, 1993). Thus, the potential of any undigested protein in faeces, as a result of the poor quality silage fed during project AM0110, contributing to ammonia emission during animal housing is low. This may explain why a lower proportion of the feed N intake was volatilised as ammonia.

Table 6. Mean ammonia loss per tunnel^{-1} during period 1 as a percentage of the feed N input.

	WA0632 Year 1	WA0632 Year 2	AM0110
SOLID	17	18	9
LIQUID	22	23	14

On the other hand, given the higher N input during WA0632 and consequently higher N excretion, it is possible that there was surplus N in the diet. Matching N intake to N requirement is an option to explore in minimising N losses from livestock and thereby potentially reducing NH_3 emission. This could be achieved by increasing feed quality and level of production and matching or synchronising the availability of N and energy in the (TAMMINGA, 1991). The accomplishment of this approach may be aided by the use of one of the newly developed protein evaluation systems such as the Dutch intestine-digestible protein system DVE (darm veteerbaar eiwit) described by BERENTSEN *et al* (1993).

Comparison of results with existing literature

Table 7 shows how the results from WA0632, AM0110 and previous work under project WA0618 compare with the UK ammonia inventory figures.

Table 7. Mean emission factors during housing (g NH_3-N lu^{-1} d^{-1})

	1999 UK NH_3 inventory*	WA0618		WA0632 *Year 1*	WA0632 *Year 2*	AM0110 (Period 1 only)
Beef cattle (litter)	27.6	39.1, 6.6, 10.1	Period 1	41.0	51.7	19.1
			Period 2	37.7	41.9	
			Average per period	39.3	46.8	
Beef cattle (cubicles)	36.6	-	Period 1	54.1	72.2	28.7
			Period 2	55.6	65.9	
			Average per period	54.8	69.0	

**Data from recent UK ammonia emission inventory update project, AM0108.*

Emission factors measured under WA0632 were higher than the inventory figures whereas those measured under AM0110 were lower. There was a lot of variation between the emission factors measured during WA0632 and AM0110 ranging from 19.1 to 51.7 g NH_3-N lu^{-1} d^{-1} on the solid system and 28.7 to 72.2 g NH_3-N lu^{-1} d^{-1} on the liquid system. This large range of emission factors consequently has a great impact on the UK ammonia inventory total for housing losses. Using the lowest and highest emission factors measured during WA0632 and AM0110 on both the solid and liquid systems, respectively, gives a range of 35.94 to 59.16 kt NH_3-N for cattle housing in the UK during 1999. The inventory total of 41.58 kt for housing losses is within this range.

Data compiled by GROOT KOERKAMP *et al* (1998) on emissions from livestock buildings in Northern Europe (UK, Netherlands, Denmark and Germany) are summarised in Table 8 (corrected to g NH_3-N d^{-1}).

Table 8. Mean emission of ammonia for various housing systems for cattle in the UK and a range of emissions from Northern Europe (UK, Netherlands, Denmark and Germany).

	g NH_3-N $head^{-1}$ d^{-1}			**g NH_3-N lu^{-1} d^{-1}**		
System and animal type	UK mean	N. Europe range	WA0632/ AM0110 range	UK mean	N. Europe range	WA0632/ AM0110 range
Dairy cows (litter)	7.5	1.3-23.4	-	6.2	6.2-21.4	-
Dairy cows (cubicles)	29.9	23.7-48.0	-	25.2	20.2-42.4	-
Beef cattle (litter)	11.6	6.3-11.6	10.6-29.3	11.5	10.3-11.6	19.1-51.7
Beef cattle (cubicles)	-	-	16.0-40.1			28.7-72.2

Comparing these figures with the results from WA0632 and AM0110 (Tables 5 and 8), firstly for g NH_3-N $head^{-1}$ d^{-1}, the measurements made under project AM0110 lie within or are lower than the range for Northern Europe and those from WA0632 are in the upper range or higher. The figures for cubicles are comparatively higher than from litter whether compared against dairy or beef cattle cubicle systems, as found in WA0632 and AM0110.

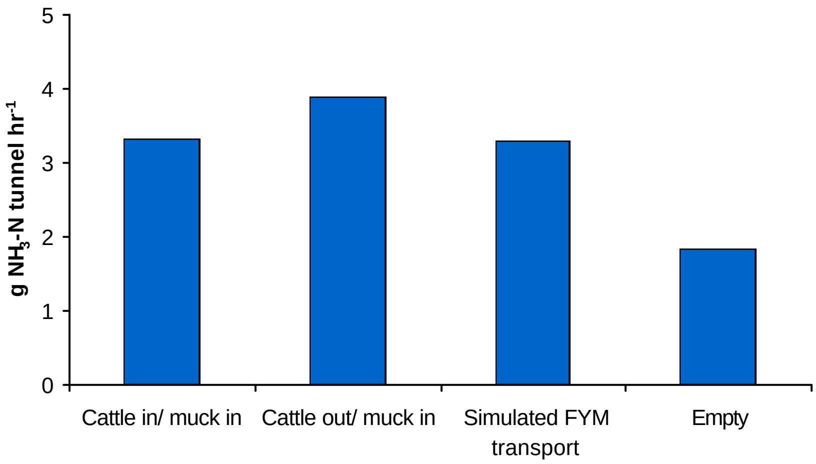
Results from GROOT KOERKAMP *et al* (1998) expressed in g NH_3-N d^{-1} lu^{-1} are similar to those expressed on a per head basis indicating that the animals in the experiments were approaching 500 kg liveweight. The animals used in WA0632 and AM0110 were much smaller (maximum initial liveweight of ~260 kg) and thus the results when expressed per livestock unit are generally greater.

Results from AM0110 were generally within, or lower than, the ranges of values presented by GROOT KOERKAMP *et al* and the UK ammonia inventory, whereas those measured during WA0632 were generally higher (Tables 7 and 8). Low emissions were measured during AM0110 and it is probable that results from WA0632 are more typical. It is possible that measurements made under WA0632 were higher than those measured by GROOT KOERKAMP *et al* and the UK ammonia inventory because the ventilation rate used in the housing systems was almost six times that of the mean ventilation rates measured for cattle systems across Northern Europe (341 m^3 hr^{-1} 500kg liveweight) by SEEDORF *et al*, 1998.

AMMONIA LOSSES DURING MOVEMENT OF SOLID MANURE FROM HOUSING TO FIELD STORAGE HEAP (AM0110 PERIOD 1)

Ammonia-N losses during the process of moving the solid manure from the housing systems to the field storage heaps are detailed in Figure 2. The rate of loss was similar during measurements with/without the cattle in the tunnels and during simulated movement of FYM from the housing systems to the field storage heaps: 3.3 g NH_3-N $tunnel^{-1}$ hr^{-1} was measured during simulated transport of the FYM produced during period 1. This compares with a mean rate of loss of 1.9 g NH_3-N $tunnel^{-1}$ hr^{-1} measured prior to the daily addition of straw during period 1. A significant emission rate was also measured after the manure had been removed from the buildings as there was still a wet, dirty surface despite removal of all straw and faecal material.

Figure 2). Period 1 NH_3-N losses during transfer of FYM from the building to the storage (31st January 2001).



STATISTICS

Analysis of variance (ANOVA) was carried out to determine i) any significant difference between the solid and liquid management systems during period 1 of each year ii) any significant differences between the solid and liquid management systems using measurements fom all of the years as replicates, iii) any significant differences between the losses from year to year, and iv) any interaction between the management system and the year.

Statistical analysis showed that during period 1 of the housing phase, emissions from the liquid system were significantly greater than those from the solid system during WA0632 but not AM0110 (Table 9).

Table 9. Summary of statistical analyses during period 1 of the housing phase of WA0632 and AM0110

	Kg NH_3-N lu^{-1} d^{-1}	Significance and error terms	
		Probability	S.E.D.
WA0632 Yr 1			
(94 days)			
Solid	41.0	0.03	0.550
Liquid	54.1		
WA0632 Yr 2			
(93 days)			
Solid	51.7	0.002	0.050
Liquid	72.2		
AM0110			
(92 days)			
Solid	19.1	NS	2.20
Liquid	28.7		

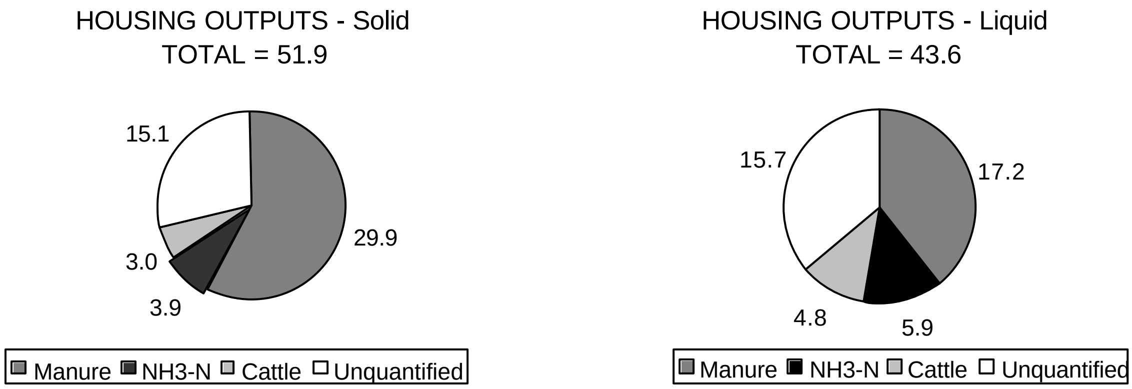
Results from the ANOVA using data collated during period 1 of all years of the housing phase showed that the liquid system resulted in a significantly (P=0.04, s.e.d.= 3.01) greater mean loss of 51.6 g NH_3-N lu^{-1} d^{-1} compared to 37.3 g NH_3-N lu^{-1} d^{-1} from the solid system over the three years.

Mean housing losses during AM0110 (23.9 g NH_3-N lu^{-1} d^{-1}) were significantly different from both years of WA0632 (P=0.05, s.e.d. = 7.29). However, losses during WA0632 year 1 (47.5 g NH_3-N lu^{-1} d^{-1}) were not significantly different from year 2 (62.0 g NH_3-N lu^{-1} d^{-1}. There was no interaction between the management system and the year.

3.3 N BUDGET (AM0110 PERIOD 1)

Mean total N inputs during period 1 for the solid and liquid systems were 51.9 and 43.6 kg per $tunnel^{-1}$, respectively (Figure 3); the greater input to the solid system being as a result of the straw input. Ammonia-N emission was lower from the solid system (3.9 kg) than the liquid system (5.9 kg). Cattle total N output (in the animal) from each system was calculated assuming 28 g N kg LWG (SCHULZ *et al.,* 1974). Unquantified losses were similar for each system and could be due to errors associated with measurements of NH_3 volatilisation, manure N, feed analysis, assumed N output in the animals as well as other loss pathways not measured, e.g. N_2O and N_2.

Figure 3. Housing total N outputs (kg) during period 1 of AM0110 for solid and liquid manure management systems.



The input of straw into the solid system in turn increased the total N output from the housing phase. The higher total N output from the solid system may also be attributed to lower NH_3-N losses during animal housing. Thus 30.0 kg and 17.2 kg of total N were removed in the manure produced during period 1 of the solid and liquid systems, respectively. These figures equate to 58% and 39% of the initial total N input. Of the total N output from the housing phase, 4.6 kg and 5.7 kg was present as NH_4^+-N in the solid and liquid systems, respectively.

3. CONCLUSIONS

It was unfortunate that the foot and mouth outbreak prevented measurements being carried out to the end of the winter housing period. However, it was possible to compile an N budget for the first half of the housing period, thus producing valuable results to add to, and compare against, those measured under project WA0632 and the UK ammonia inventory:-

- ? The feed N intake on both the solid and liquid systems was 208 g lu^{-1} d^{-1}, this being much lower than during project WA0632.
- ? N output in the manure was much lower during AM0110 than WA0632 with a mean of 17.2 kg of N (75 g N lu^{-1} d^{-1}) removed from the liquid system and 30.0 kg of N (133 g N lu^{-1} d^{-1}) from the solid system.

? Ammonia-N losses from the solid manure system were lower (19.1 g lu^{-1} d^{-1}) than from the liquid manure system (28.7 g lu^{-1} d^{-1}) during period 1 of the housing period.

? The rate of ammonia-N loss was reduced from 0.9 to 0.7 g lu^{-1} hr^{-1} following the daily addition of straw.

? Ammonia-N losses from both the solid and liquid systems were *c.* 50% and 40% of those measured during WA0632 year's 1 and 2, respectively.

? A lower proportion of the feed N intake was lost as ammonia-N during this project (*c.* 10%) than during WA0632.

? A common emission unit was calculated for period 1 of the housing periods of WA0632 and AM0110: a mean of 0.2 and 0.3 kg NH_3-N was emitted per kg N excreted on the solid and liquid systems, respectively.

? Emission factors measured under WA0632 were higher than the inventory figures whereas those measured under AM0110 were lower.

During this project, the N intakes were comparatively lower than during project WA0632 due to a low N content in the silage. This resulted in low N excretion by the cattle consequently reducing NH_3 emission. Furthermore, a lower proportion of the feed N intake was lost as ammonia suggesting that a higher proportion of the feed was lost as undigested protein in the faeces, i.e. in a form that is not readily hydrolysed to promote ammonia volatilisation.

Despite the variations in silage quality and thus N intake across the years, a common emission unit was calculated on the solid and liquid management systems throughout all housing years. A consistent loss of 0.2 and 0.3 kg NH_3-N per kg N excreted was measured from the solid and liquid systems, respectively. This suggests that it may be possible to predict ammonia emission from N excretion. This project has therefore highlighted the need for detailed quantitative and qualitative information on dietary N intake and the effect that subsequent N assimilation by the animals has on N excretion and ammonia emissions.

5. IMPLICATIONS FOR DEFRA

The results of this project have highlighted the influence that N intake, N retention and hence N excretion by animals, has on ammonia emission from housing systems. The coupling of DEFRA projects studying the effects of diets on N intake, assimilation and N excretion with robust ammonia emission measurements is needed. Of particular interest in this project is the discovery of a common ammonia emission unit which has implications for modelling. This may be coincidental, but this relationship should be explored further. Work is also needed to measure ammonia losses for animals at different stages of animal production and types of production system.

The effect of straw on reducing ammonia emissions has been observed both during WA0632 and AM0110 and provides an opportunity to abate ammonia emission. This avenue is being explored under project AM0103 where the effects of additional or targeted straw usage on ammonia emissions from housed livestock will be studied.

The results from AM0110 are invaluable in adding to the information already gathered under project WA0632 and the UK ammonia emissions inventory. However, once successful strategies for reducing losses during the housing phase have been fully understood and established, whole system effects need to be assessed. Losses from the whole management system, i.e. housing, storage and landspreading have already been studied under project WA0632 and this work has highlighted the importance of protecting upstream losses, i.e. housing losses, against down stream losses (i.e. during storage and following land spreading).

6. OUTPUTS

The polytunnel facility and associated manure storage facilities have proved to be an excellent demonstration tool for students, overseas visitors, research workers and DEFRA officials.

7. REFERENCES

AGRICULTURAL DEVELOPMENT AND ADVISORY SERVICE/MINISTRY OF AGRICULTURAL FISHERIES AND FOOD. 1985. Beef cattle housing. Booklet 2512, p. 11.

ASTERAKI, E.J., MATTHEWS, R.A. & PAIN, B.F. 1997. Ammonia emissions from beef cattle bedded on straw. *Proceedings of the International Symposium, Vinkeloord, The Netherlands, 6th-10th October, 1997,* **1**: 343-347.

BERENSTEN, P.B.M, GIESEN, G.W.J & SPEELMAN. 1993. Economic and environmental effects of a new protein evaluation system in dairy farming. *Journal of Dairy Science,* **76**: 2332-2343.

BRADSTREET, R.B. 1965. The Kjeldahl method for organic nitrogen. *Academic Press.*

BRISTOW, A.W., WHITEHEAD, D.C. & COCKBURN, J.E. 1992. Nitrogenous constituents in the urine of cattle, sheep and goats. *Journal of the Science of Food and Agriculture,* **59**: 387-394.

BUSSINK, D.W. & OENEMA, O. 1998. Ammonia volatilization from dairy farming systems in temperate areas: a review. *Nutrient Cycling in Agroecosystems,* **51**: 19-33.

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., PEDERSON, S., TAKAI, H., JOHNSEN, J.O. & WATHES, C.M. 1998. Concentrations and emissions of ammonia in livestock buildings in northern Europe. *Journal of Agricultural Engineering Research.* **70**:79-95.

MISSELBROOK, T.H., CHADWICK, D.R., PAIN, B.F. & HEADON, D.M. 1998. Dietary manipulation as a means of decreasing N losses and methane emissions and improving herbage N uptake following application of pig slurry to grassland. *Journal of Agricultural Science,* **130**: 183-191.

MISSELBROOK, T.H., VAN DER WEERDEN, T.J., PAIN, B.F., JARVIS, S.C., CHAMBERS, B.J., SMITH, K.A., PHILLIPS, V.R. & DEMMERS, T.G.M. 2000. Ammonia emission factors for UK agriculture. *Atmospheric Environment,* **34**: 871-880.

OLDHAM, J.D. 1984. Protein-energy interrelationships in dairy cows. *Journal of Dairy Science,* **67**: 1090-1114.

RSPCA. 2000. Welfare standards for beef cattle.

SCHULZ, E., OSLAGE, H.J., DAENICKE, R. 1974. Investigations on the carcass composition and nitrogen and energy retention of growing, fattening bulls [Untersuchungen ber die Zusammensetzung der Körpersubstanz sowie den Stoff-und Energieansatz bei wachsenden Mastbullen]. *Fortschritte in der Tierphysiologie und Tierernährung.* Verlag Paul Parey. No. 4, pp. 1-70.

SEEDORF, J., HARTUNG, M., SCHRÖDER, M., LINKERT, K.H., PEDERSON, S., TAKAI, H., JOHNSEN, J.O., METZ, J.H.M., GROOT KOERKAMP, P.W.G, UENK, G.H., PHILLIPS, V.R., HOLDEN, M.R., SNEATH, R.W., SHORT, J.L., WHITE, R.P. & WATHES, C.M. 1998. A survey of ventilation rates in livestock buildings in Northern Europe. *Journal of Agricultural Engineering Research.* **70**:39-47.

SMITS, M.C.J., VALK, H., MONTENY, G.J. & VAN VUUREN, A.M. 1997. Effect of protein nutrition on ammonia emission from cow houses. In: JARVIS, S.C. & PAIN, B.F. (*eds.*) 1997. Gaseous nitrogen emissions from grasslands. CAB International, Wallingford, UK, pp. 101-107.

SOFFE, R.J. (ed.) 1995. Primrose McConnell's. The Agricultural Notebook. 19th edition. Blackwell Science Ltd., pp. 221.

TAMMINGA, S. 1991. Nutrition management of dairy cows as a contribution to pollution control. *Journal of Dairy Science,* **75**: 345-357.

TAMMINGA, S., KETELAAR, R & VAN VUUREN, A.M. 1991. Degradation of nitrogenous compounds in conserved forages in the rumen of dairy cows. *Grass and Forage Science,* **46**: 427-435.

VAN VUUREN, A.M., KROL-KRAMER, F., VAN DER LEE, R.A. & CORBIJN, H. 1992. Protein digestion and intestinal amino acids in dairy cows fed fresh *Lolium perenne* with different nitrogen contents. *Journal of Dairy Science,* **75**: 2215-2225.

WHITEHEAD, D.C. & RAISTRICK, N. 1993. Nitrogen in the excreta of dairy cattle: changes during short-term storage. *Journal of Agricultural Science,* **121**: 73-81.

8. PROJECTS CITED

AM0108 - Updating the ammonia emissions inventory for the UK for 1999

AM0110 - Additional measurements of ammonia from beef cattle housed in straw- and slurry-based housing systems

WA0618 - Emissions from farmyard manure based systems for cattle

WA0632 - Ammonia fluxes within solid and liquid manure management systems

WA0706 - Ammonia and nitrous oxide emissions from utilisation of slurry and FYM from beef cattle

Please press enter