INSTITUTE OF AGRICULTURAL ENGINEERING

Anglo-Dutch experiments on odour and ammonia emissions from landspreading livestock wastes

B.F. Pain

IGAP Institute for Grassland and Animal Production

J.V. Klarenbeek

IMAG Institute of Agricultural Engineering

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Anglo–Dutch experiments on odour and ammonia emissions from landspreading livestock wastes.

B.F. Pain[1] and J.V. Klarenbeek[2]

Summary

Three methods were used in the collection of odours and in the measurement of ammonia emissions from application of cattle, pig and poultry slurry and poultry manure to grassland. A method developed at IMAG was used in measurements during spreading with a conventional tanker and two methods developed at IGAP following spreading. One was based on a system of small wind tunnels and was used in the experiments on small plots under controlled conditions, whilst the second, a micrometeorological technique, was used for larger areas under ambient conditions. Odour concentration in air samples was measured with two dynamic dilution olfactometers at IMAG.

Both odour and ammonia emission was greater from poultry than from cattle or pig slurry. Ammonia emission was lowest from cattle. There were also differences in the pattern of emission with time between the different types of waste. Emissions during the spreading operation represented less than 1% of the totals. However odour threshold values measured during spreading were up to ten times those following spreading.

The research activities followed on from the existing Anglo–Dutch Agreement on Farm Wastes established in 1980.

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[1] Institute for Grassland and Animal Production (IGAP), Hurley, Maidenhead, Berkshire, United Kingdom.
[2] Institute of Agricultural Engineering (IMAG), Wageningen, The Netherlands.

1. Introduction.

1.1. Extent of the problem.

In common with several other European countries, concern about the environmental impact of volatile emissions from livestock wastes has increased in recent years in both the United Kingdom and the Netherlands. The two major problems are offensive odours and ammonia.

In both countries, livestock farming is a major source of offensive odours. In the UK, the total number of complaints from the public was 2200 in 1984–'85. Over 50% are associated with pig farms and nearly 50% of the total results from spreading slurry or manure on land. In the Netherlands, the major problems are associated with pig and poultry farms.

Ammonia emission is of particular concern in the Netherlands since it may not only influence atmospheric chemistry and accelerate acid deposition but also represents a decrease in the fertiliser value of slurries and manures. The total ammonia emission increased by an average of 46% over Europe as a whole between 1950 and 1980 compared with 55% in England and Wales and 135% in the Netherlands (Kruse et al., 1986).

1.2. Nationally funded programmes.

In the last few years, the Netherlands has set up a wide–ranging programme of research aimed at reducing the emissions of ammonia and of odours from agriculture. The emphasis is on measuring and controlling emissions from livestock buildings and from slurry and manure stores.

In the UK, the Ministry of Agriculture, Fisheries and Food has for several years funded research at AFRC Engineering and elsewhere on the reduction of odours from farm wastes, and at IGAP on ammonia emissions as part of a programme on improving the efficiency of nitrogen usage. More recently, the Ministry has in addition funded a 3–year research programme specially on reducing odours during land spreading of slurries. This programme is currently being conducted at IGAP, AFRC Engineering, ADAS and Silsoe College.

1.3. Background to Anglo–Dutch collaboration.

Quantitative assessment of odour and ammonia emission during and following the application of slurry to land is a pre–requisite of the development of management guidelines, machinery, treatment processes, etc. for reducing emissions. Such techniques require suitable methods for collection and subsequent measurement of odour and ammonia concentration. For several years, two techniques have been in use at IGAP for the measurement of ammonia emissions in the field. One is suitable for studies on small plots, the other for measurements from larger land areas. Both have recently been adapted for the quantitative collection of samples of odorous air following the application of slurries to land. Concurrently, advanced techniques, based on dynamic dilution olfactometry have been developed by IMAG for measuring odour concentrations. Also, at IMAG, a technique has been developed for measuring emissions during the spreading operation.

During discussions between British and Dutch workers in 1986, it was agreed to establish a collaborative programme to allow the expertise and techniques from both countries to be focused on problems of odour and ammonia emission. This followed on from the existing Anglo–Dutch Agreement on Farm Wastes which was established in 1980 by both ministers of agriculture. An IMAG–5 olfactometer was made available for loan to the UK in December 1986, and agreement reached for a team from the UK to visit the Netherlands with equipment to conduct a series of joint experiments. This document reports on these experiments, which were conducted in the Wageningen area between 27 May and 20 June 1987, and makes recommendations for future work.

1.4. Objective

To compare the rates of odour and ammonia emission during and following the application of different types of livestock wastes to grassland.

2. Materials and methods.

2.1. Staff.

Research workers and others representing 5 organisations collaborated in the experiments;

- Institute for Grassland and Animal Production (IGAP), Hurley, Maidenhead, Berkshire SL6 5LR, UK.

Dr. B.F. Pain	Project Leader UK.
Mr. D.R. Lockyer	
Mr. J.H. Skinner	
Mr. N. Raistrick	

- Institute of Agricultural Engineering (IMAG), Mansholtlaan 10-12, 6708 PA Wageningen, NL.

Ing. J.V. Klarenbeek	Project Leader NL.
Ing. M.A. Bruins	Operations Coordinator
Ir. M.J.C. de Bode	
Ing. J.W.M. Huis in 't Veld	
Mrs. C.J.M. Schmidt-van Riel	Head of Laboratory
Mr. G. Kupers	
Mr. J.A. Gelok	Olfactometer Operator
20 odour panellists	by Werknet temporary employment office

- Ministry of Agriculture, Fisheries and Food, Agricultural Development and Advisory Service, (ADAS), Liaison Unit, Wrest Park, Silsoe, Bedford MK45 4HS, UK.
  Mr. C.R. Clarkson
  (present address: IGAP, Hurley, Maidenhead, Berkshire SLR6 5LR, UK.)

- Institute for Agricultural Engineering Research (AFRC Engineering), Wrest Park, Silsoe, MK45 4HS. UK.
  Dr. V.R. Phillips

- Project Research, O.Z.-Achterburgwal 14, 1012 DM Amsterdam, NL. (under contract to IMAG)
  Ir. A.Ph. van Harreveld
  Mr. A. Kuiper
  Mr. P. de Bakker

2.2. Site.

The experiments were conducted on a cattle and pig farm located about 20 km north of Wageningen which is owned by J. van der Top. The field used was sown to a predominantly ryegrass sward and covered an area of approximately 4.5 ha. The location of the experiments within the field is given in fig. 1.

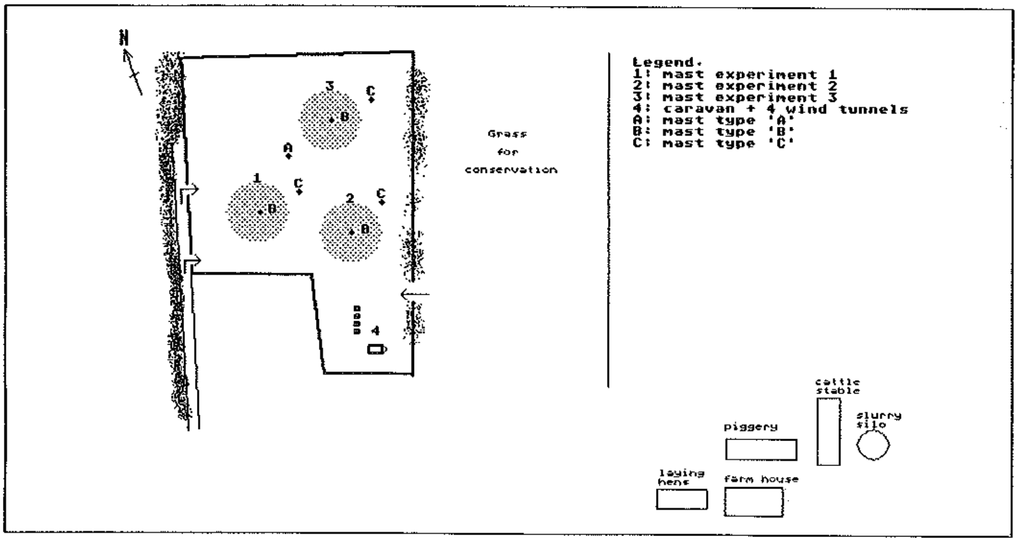

Figure 1. Experimental site.

2.3. Slurry and manure.

Pig, cattle, poultry manure was used in the experiments.

2.3.1. Pig slurry.

This was obtained from the piggery on the farm. Pigs were fattened up to 120 kg live weight on meal comprising wheat, tapioca and soya bean pulp. For feeding to the pigs the meal was mixed with a minimum amount of water in troughs. A small amount of chopped straw was used as bedding in the pens, the floors of which were partially slatted so that the slurry was stored in a pit beneath the building. A provision was made to withdraw the slurry from outside the building by using a vacuum tanker.

2.3.2. Cattle slurry.

Dairy cow slurry was obtained from the same farm. The building housed 50 milking cows during the winter. The cattle lay on plastic mats with minimal bedding and the passageways were slatted so that the slurry was stored in below-ground channels. The slurry drained to the end of the building from where it was pumped to a 500 m^3 capacity above-ground, circular store constructed of concrete. Slurry was withdrawn from the store via a reception pit. Parlour and yard washings were piped to a ditch.

2.3.3. Poultry slurry and manure.

These wastes were collected at the experimental poultry station 'COVP' at Beekbergen from the following houses which were designed to measure the ammonia emissions from different housing systems;

-COVP 5: Broilers on an uninsulated concrete floor with litter of chopped straw.

-COVP 8: Layers in two-tier batteries with manure removal belts equipped with an air-drying system. The droppings were dried on the belts beneath the cages, removed from the house once a week to a roofed store and handled as manure of about 60% total solids (TS).

-COVP 9: Layers in two-tier batteries with manure removal belts as for COVP 8 but with no drying system. Droppings were removed twice a week and stored in a tank as thick slurry. Prior to emptying, this was diluted with water (3:1) so that it could be spread on land by a vacuum tanker.

-COVP 10: Layers in two-tier batteries with droppings stored in a pit beneath the cages. Water was added before emptying the pit so that the waste could be pumped out as slurry. In table 1, COVP 10 is also referred to as 'poultry'.

2.4. Measurement of ammonia and odour emissions following spreading.

Two methods were used in the field for the measurement of ammonia emissions and for the collection of samples of air for olfactometry.

2.4.1. Wind tunnel method.

The wind tunnel system was originally designed for use in the measurement of field losses of ammonia through volatilisation and was described by Lockyer (1984). Four tunnels were used, each consisting of a transparent polycarbonate sheet which was flexed to cover an area of 0.5 x 0.2 m and 0.45 m at its highest point from the ground. This canopy was connected to a steel duct housing a variable speed axial fan and a vane anemometer. The design allowed air speed through the canopy to be controlled over the range normally encountered under field conditions and ensured that natural sward conditions were influenced as little as possible. The volumes of air passing through the tunnels, together with soil and air temperatures, were recorded on a datalogger.

For the ammonia measurements, diaphragm pumps were used to draw air at 5 $l.min^{-1}$ through absorption flasks each comprising a test tube (100 cm^3) with a ground glass neck fitted with a Drechsel bottle head supporting a gas dispersion tube. The traps contained orthophosphoric acid (0.002 M). Control of the air flow was achieved by using a stainless steel needle valve and a 0.5–5 l air flow meter. One absorption flask received outlet air from the tunnel and a second flask sampled inlet air to enable background NH_3 levels to be measured. Both absorption flasks were positioned as close to the tunnel inlet/outlet as possible to reduce to a minimum any sorption of NH_3 that might occur in the supply tubing. All other peripheral equipment was housed in a mobile caravan sited near to the tunnels.

For odour collection, samples of air drawn through a tunnel were collected into FEP sampling bags of approx. 60 l capacity. A Metal Bellows pump (MB 158–E) was used to draw air through a length of FEP tubing fixed within the steel duct, upstream of the fan, filling duplicates bags within 5–10 minutes.

The datalogger was used to record data for wind speeds and temperatures on magnetic tape. These data were subsequently transferred to the IMAG VAX mainframe computer using a BBC microcomputer and tape reader.

2.4.2. Micrometeorological methods.

This method was used to measure emissions from larger areas to which slurry was applied by farm scale spreading machinery. The theory underlying the method is discussed elsewhere (Denmead, 1983). The method assumes the vertically integrated product of wind speed and ammonia concentration divided by the radius of the treated area to be equal to the ammonia flux (F) from the soil surface.

$$F = \frac{1}{x} \int_{Z_0}^{Z_p} \bar{u}\bar{c}\, dz$$

where $\bar{u}$ and $\bar{c}$ are the mean wind speed and ammonia concentration over a particular sampling interval respectively, and x the fetch or radius of the treated area. The integration limit Z_p is the height at which gas concentration has decreased to its normal background level and Z_0 the height at which the wind speed falls to zero. In practice, the mass balance is determined from the differences in amount of gas driven by the wind across the upwind and downwind boundaries of an area. This involves the measurement of wind speed and concentration of gas in the air at different heights above the area at its upwind and downwind boundaries in order to obtain profiles of wind speed and gas concentration over each sampling period. Normally, it is also necessary to record the wind direction to calculate the appropriate fetch for each interval but, in the current experiments, this requirement was avoided by measuring gas concentrations at the centre of circular plots. Although it is feasible to measure ammonia concentration at a sufficient number of heights (6 in this experiment) to construct a concentration profile, this was not practicable for odour because of the limited number of olfactometric assessments that could be made each day. However, previous theory and experimentation (Wilson, 1982) indicate that, as long as certain conditions relating to the size and uniformity of the area surrounding the plot are met, it is possible to infer the surface flux from the measurements at just one height, termed ZINST, which is only dependent on Z_0 and the plot radius or fetch. The method for determining Z_0 for a particular site, and hence ZINST, is described by Wilson et al. (1982), together with the calculations for determining flux or emission by this method.

The equipment consisted of several masts 3 m high, made from aluminium tubing (64 x 4 mm), with 1 m long side arms supporting either cup anemometers or absorption flasks. Three types of masts were used in the experiments.

–Type A: This was used in the measurement of wind speed at 6 heights above the experimental area. Side arms supported anemometers at 0.35, 0.75, 1.3, 1.9, 2.5, and 3.3 m. The analogue output from each anemometer was recorded on a battery operated datalogger (Grant Instruments, Squirrel, 7 channel) placed at the base of the mast. The scanning interval was 1 s, mean values being recorded every 3 min (the mean of 180 scans).
There was also a provision to monitor wind direction, by means of a wind vane mounted on top of the mast, and ambient temperatures with thermocouples and a second datalogger.

–Type B: This was similar to type A except that the side arms supported ammonia absorption flasks and there was a provision to collect samples of air for olfactometry. For ammonia measurement, air was drawn through each absorption flask at 5 $l.min^{-1}$ by individual diaphragm pumps. Air flow was controlled by a stainless steel needle valve fitted to a flow meter. The actual volume of air drawn through each flask during any sampling interval was measured by a bellows–type gas meter. The 6 pumps, flow meters and gas meters were contained in a rain proof box placed at the periphery of the plot.
For odour collection, FEP sampling bags were inflated via FEP tubing by the Metal Bellows pump placed at the base of the mast. The open end was fixed on the mast at height ZINST and 6 bags were filled simultaneously over 60 min sampling periods.

-Type C: This type was identical to type B except that there were only 3 absorption flasks and associated apparatus. It was used in the measurement of the background levels of ammonia and odour in air immediately upwind of the treated plot.

At intervals, data from the logger were down-loaded to an Epson microcomputer in the field. Subsequently the data were transferred (as an ASCII file) to disc through a BBC microcomputer and from there to the IMAG VAX mainframe computer for processing using software developed at IGAP. Ammonia concentratiòn data was entered via the VAX keyboard.

2.5. Measurement of ammonia and odour emission during spreading.

Odour and ammonia emission was measured during the spreading of slurry with a conventional high profile tractor-drawn vacuum tanker. In general, emission (E) arising from spreading itself is measured directly behind the spreading machine and calculated by:

$$E = A \int_{t_0}^{t_n} \bar{u}\bar{c}\, dt$$

where A is the cross sectional area of the plume, $\bar{u}$ the sum of the mean wind speed and speed of travel over the sampling interval and $\bar{c}$ the aerial concentration of the substance under consideration. The integration limits t_0 and t_n represent the start and the end sampling period. In case of the traditional vacuum tanker equipped with a circular spreading plate, the cross sectional area is calculated by:

$$A = 1/2\,\pi r^2$$

To establish odour and ammonia concentrations during spreading, a tubular frame with a cross sectional area of 40 m^2 supporting ammonia absorption flasks at 16 points and odour collection tubes at 5 points was mounted on the front of a Land Rover (fig. 2). During experimentation, the Land Rover was driven behind the slurry spreader with the frame in the wake of the slurry plume. Pumping equipment, similar to that described in paragraph 2.4.1. with the exception that the 220 V diaphragm pump was replaced by a 12 V rotary vane air pump, was housed inside the Land Rover and used to draw air through the absorption flasks and to inflate FEP bags with samples of odorous air.
By always spreading upwind, the total volume of air flowing through the sampling frame during the spreading operation is calculated as:

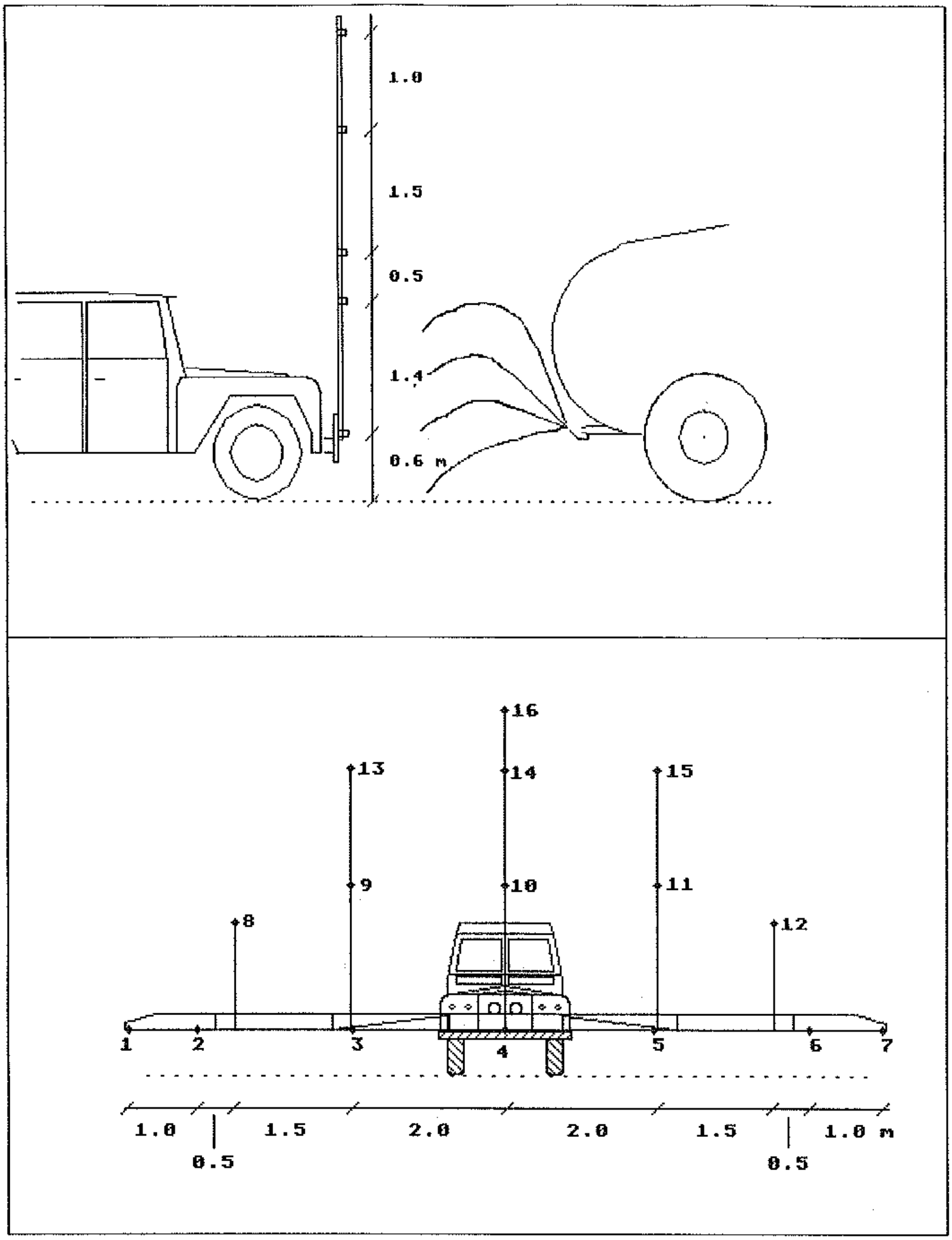

Figure 2. Side view and front view of sampling frame.

air volume (m^3) = (travel speed ($m.s^{-1}$) + wind speed ($m.s^{-1}$)) x cross sectional area of the frame (m^2) x spreading time (s).

Multiplying by the mean ammonia concentration or odour threshold value gave an estimate of the total emission which were subsequently expressed as kg NH_3 and odour units.m^{-3} slurry spread.

2.6. Olfactometry.

Two dynamic dilution olfactometers (IMAG–4) installed in a suitable room at IMAG were used to determine odour threshold values for the air samples collected in the FEP bags. Each olfactometer was equipped with two sniffing ports and were of the forced choice type with odourless air being offered to the panellists through one port and the diluted sample air through the other. Eight to ten panellists were presented with 5 dilution levels and 1 blank (odour–free air) in random sequence, each presentation being offered 3 times during the assessment. Calculation and presentations of dilutions and blanks as well as the collection of panellist responses were controlled by a Hewlett Packard HP–86B microcomputer.

Odour concentration (odour units.m^{-3}) was expressed as the number of dilutions required to reach a threshold level value i.e. the dilution at which 50% of the panellists could just perceive an odour.

2.7. Ammonia analysis.

Ammonia was analysed according to the Dutch standard method for analysis of NH_4–N in liquids, NEN 6472, which is equivalent to ISO/DIS 7150. This is a modified Berthelot reaction using dichloroisocyanurate and salicylate. After measuring the concentration at 655 nm, the original ammonia concentration in air can be calculated.

3. Experiments with small wind tunnels.

Four experiments (table 1) with the wind tunnels were completed, air speed being controlled at 1 $m.s^{-1}$. For each experiment, a measured volume of slurry was evenly applied by bucket or watering can to an area of grassland 0.5 x 2.0 m. Immediately after application a tunnel canopy was pinned into position over the treated area, the air lines to the ammonia absorption flasks connected and samples of air collected for odour assessment. Subsequently, the absorption flasks were changed at intervals, odour samples being taken for about 7 minutes at the start of each period of NH_3 collection.

Table 1. Outline description of the various experiments performed.

Experiment type	Experiment number	Objective	Type(s) of slurry[3]	Application rate ($m^3.ha^{-1}$)
Tunnel	T1	Measure odour and ammonia emissions after the spreading of slurry on 1 m^2 plots at recommended Dutch rates of application.	Pig Poultry Cattle Blank	17 10 17 0
	T2	Measure odour and ammonia emissions after the spreading of pig slurry on 1 m^2 plots at different rates of application.	Pig Pig Pig Blank	10 30 90 0
	T3	Replication of T1	Pig Cattle Blank	17 17 0
	T4	Measure odour and ammonia emissions after spreading on 1 m^2 plots of different type of poultry manure from the poultry experimental station 'COVP' at Beekbergen.	COVP 10 COVP 9 COVP 8 COVP 5	10 10 6 6
Mast	M1	Measure odour and ammonia emissions after the spreading of slurry on a 1,960 m^2 plot.	Cattle	15
	M2	As M1	Pig	15
	M3	Replication of M2	Pig	15
Land Rover	LR1	Measure odour and ammonia emissions during the spreading of slurry on a 1,960 m^2 plot.	Cattle	15
	LR2	As LR1	Pig	15
	LR3	Replication of LR2	Pig	15

[3] As described in paragraph 2.3

4. Experiments with 50 m diameter circular plots.

Three experiments (table 1) were conducted. Wind speeds at different heights were recorded for a period before the onset of each experiment in order to calculate height ZINST for a 25 m fetch. For each experiment, slurry was spread in parallel passes over a 50 m diameter circle using a conventional vacuum tanker. The first pass was made along the diameter of the circle (fig 3). To measure emissions during spreading, the Land Rover fitted with the ammonia and odour sampling equipment followed behind the tanker in the wake of the slurry plume. Immediately after spreading, a type B mast was erected so that the ammonia absorption flasks and the odour sampling point were located at the centre of the circle. A type C mast was erected just outside the upwind boundary of the circle to measure the background levels of ammonia. The air lines to the ammonia absorption flasks were connected and filling of 4 odour sampling bags commenced from a sampling point at height ZINST. The flow through the odour sampling pumps was controlled so that the bags were filled over a period of 1 hour. The fully inflated bags were transported to IMAG for odour assessment. The ammonia absorption flasks were changed and the odour sampling procedure repeated at intervals.

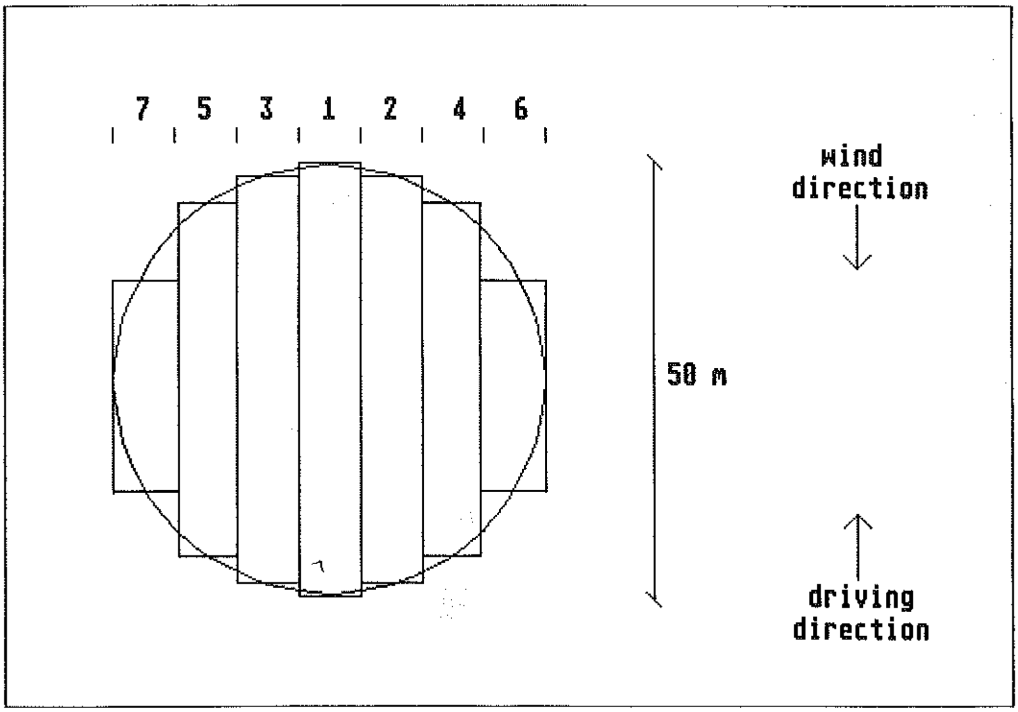

Figure 3. Scheme of spreading passes.

5. Results.

5.1. Experiment T1. Odour and ammonia emission from pig, poultry and cattle slurry.

Analyses of the slurries used in this experiment are given in table 2. The poultry slurry contained the highest concentrations of total solids, N, NH_4–N, P and Volatile Fatty Acids (VFA). The NH_4–N represented 51, 59 and 14% of the total N in pig, poultry and cattle slurry respectively.

Table 2. Tunnel experiment 1: slurry analyses.

Slurry	Pig	Poultry	Cattle
Rate of application ($m^3.ha^{-1}$)	17	10	17
Total solids (%)	15.1	16.2	10.7
Total N (%)	0.72	0.93	0.60
NH_4–N (%)	0.37	0.55	0.14
P (%)	0.35	0.54	0.15
K (%)	0.37	0.33	0.31
pH	7.2	7.2	6.7
Total volatile fatty acids ($mg.l^{-1}$)	8600	17400	5100

Table 3. Tunnel experiment 1: nitrogen applied and ammonia lost.

Slurry	Pig	Poultry	Cattle
Experimental period (days)	5	5	5
Rates of application ($m^3.ha^{-1}$)	17	10	17
Nitrogen applied:			
kg NH_4–$N.ha^{-1}$	62.9	55.0	23.8
kg total $N.ha^{-1}$	122.4	93.0	102.0
Ammonia loss:			
kg NH_3–$N.ha^{-1}$	48.8	27.1	9.7
% of NH_4–N	77.6	49.2	40.6
% of total N	39.9	29.1	9.5
kg NH_3–$N.m^{-3}$ slurry applied	2.9	2.7	0.6

Table 3 gives the details of the rate of application and the amounts of ammonia lost over 5 days of the experiments. The greatest ammonia loss (48.8 kg NH_3–

N.ha^{-1}) occurred from the pig slurry and was equivalent to nearly 40% of the nitrogen applied in the slurry or to 2.9 kg NH_3–N.m^{-3} slurry applied. The smaller total losses from poultry slurry were due mainly to a lower rate of application, loss per m^3 slurry applied was 2.7 kg NH_3–N. The smallest total loss was from cattle slurry, less than 10% of the NH_4–N applied being lost over the 5 days. Data for cumulative loss presented in figure 4, illustrate the very rapid loss of ammonia immediately after application of pig slurry. The highest rates of loss from poultry and cattle slurry were also recorded shortly after application so that losses during the first 12 hours were equivalent to 48, 39 and 62% of the total loss for pig, poultry and cattle slurry respectively.

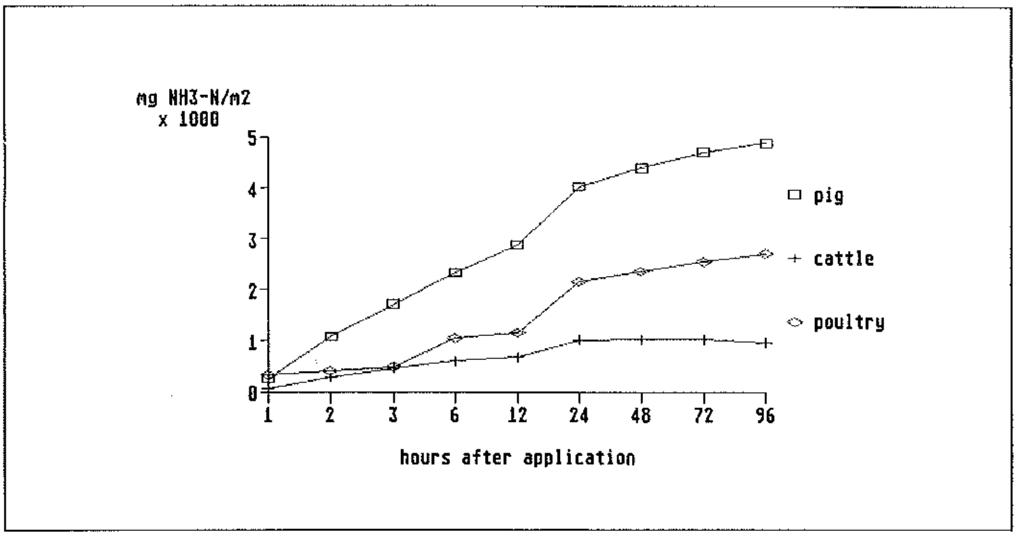

Fig 4. Accumulative ammonia emission from pig, cattle and poultry slurry. Experiment T1.

Figure 5 shows the ammonia concentrations measured at the inlet of a fourth tunnel which was included as a 'blank' with no application of slurry. The data clearly illustrate an increase in ammonia concentration in the ambient air commencing about 20 hours after the start of the experiment. This increase coincided with local farmers taking advantage of the fine weather to spread slurry on nearby fields before forecasted rain.

The highest odour threshold value (400) was obtained from a sample of air collected immediately after application (fig. 6). This rapidly decreased to levels of 100 and less within 6 hours, averaging about 45 during the remaining period.

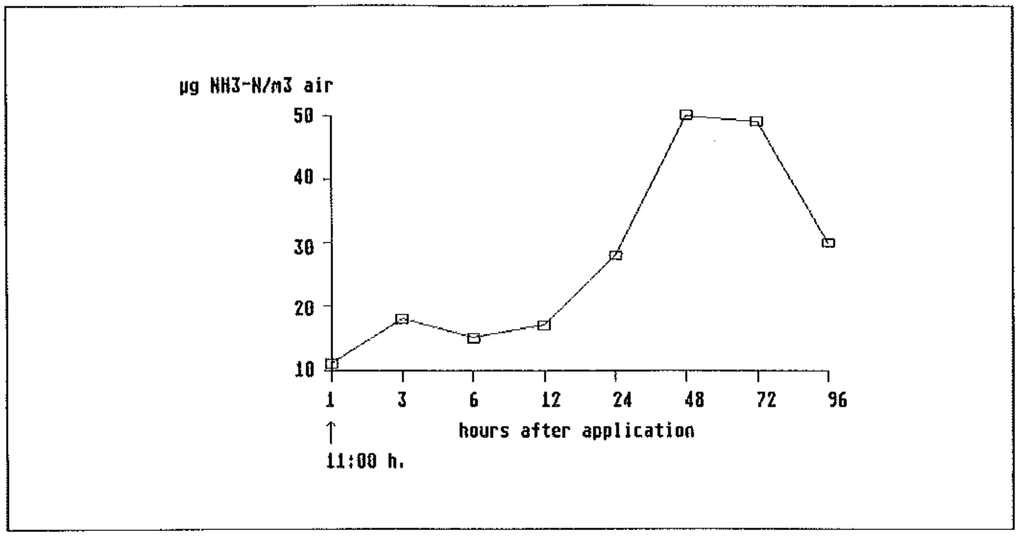

Figure 5. Ammonia concentration in ambient air.

The initial threshold values obtained for both poultry and cattle slurry were much lower than that obtained from pig slurry. However, there was evidence that odour from the former two slurries persisted longer than that from pig with the highest total odour emission (table 4) being recorded from cattle slurry. Correcting for these differences in rate of application, by expressing the results as odour units.l^{-1}slurry

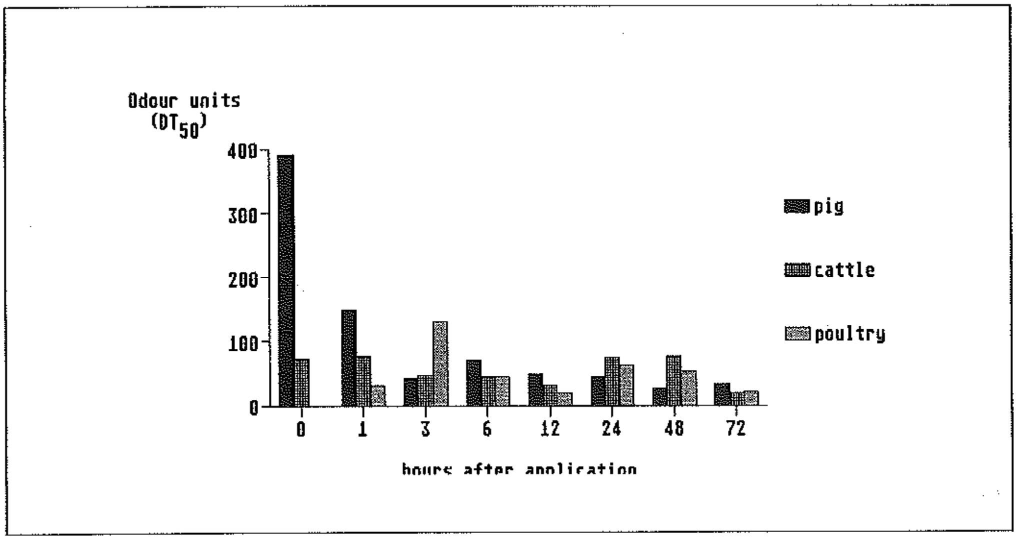

Figure 6. Odour emission from pig, cattle and poultry slurry.

applied, suggests that poultry slurry produces the greater total odour emission.

Table 4. Tunnel experiment 1: total odour emission.

Slurry	Pig	Pig	Cattle
Experimental period (days)	3	3	3
Application rate ($l.m^{-3}$)	1.7	1.0	1.7
Odour emission:			
O.U.m^{-2} land	2800 x 10^3	2702 x 10^3	3473 x 10^3
O.U.l^{-1} slurry applied	1647 x 10^3	2702 x 10^3	2043 x 10^3

5.2. Experiment T2: Odour and ammonia emissions from different rates of application of pig slurry.

Slurry analyses are given in table 5. The composition of the slurry used in this experiment was similar to the pig slurry used in experiment T1 apart from the higher N and VFA content.

Table 5. Tunnel experiment 2: slurry analyses.

Slurry	Pig	Pig	Pig
Rate of application ($m^3.ha^{-1}$)	10	30	90
Total solids (%)		13.8	
Total N (%)		0.94	
NH_4–N (%)		0.43	
P (%)		0.34	
K (%)		0.39	
pH		7.4	
Total volatile fatty acids ($mg.l^{-1}$)		14900	

Ammonia emissions over the 4 days following application totalled 23, 73 and 140 kg NH_4–N.ha^{-1} for 10, 30 and 90 $m^3.ha^{-1}$ slurry respectively (table 6). This represented 36% of the NH_4–N applied in 90 $m^3.ha^{-1}$ slurry compared with 50% for the 2 lower rates of application which resulted in a lower loss per m^3 slurry applied for the highest rate.

Table 6. Tunnel experiment 2: nitrogen applied and ammonia lost.

Slurry	Pig	Pig	Pig
Experimental period (days)	4	4	4
Rates of application $m^3.ha^{-1}$	10	30	90
Nitrogen applied:			
kg NH_3–N.ha^{-1}	43	129	387
kg total N.ha^{-1}	94	282	846
Ammonia loss:			
kg NH_3–N.ha^{-1}	22.9	73.4	139.6
% of NH_4–N	53.0	56.9	36.1
% of total N	24.4	26.0	16.5
kg NH_3–N.m^{-3} slurry applied	2.3	2.5	1.6

The pattern of NH_3 emission (fig. 7) was similar to that recorded in experiment T1 for pig slurry but with higher rates of emission persisting for a longer period at the highest rate of application.

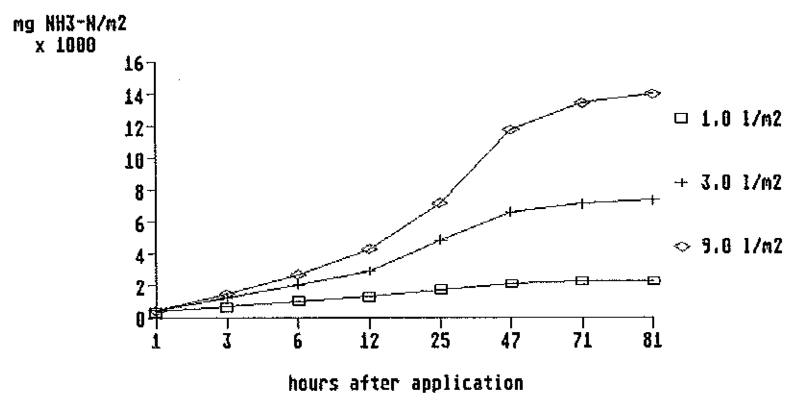

Figure 7. Accumulative ammonia emission from pig slurry at different rates of application. Experiment T2.

For odour, the major difference between the 3 rates of application was in the threshold values obtained from air samples collected immediately after application (fig. 8). These were 99, 165 and 387 odour units for the 1, 3 and 9 $l.m^{-2}$ application

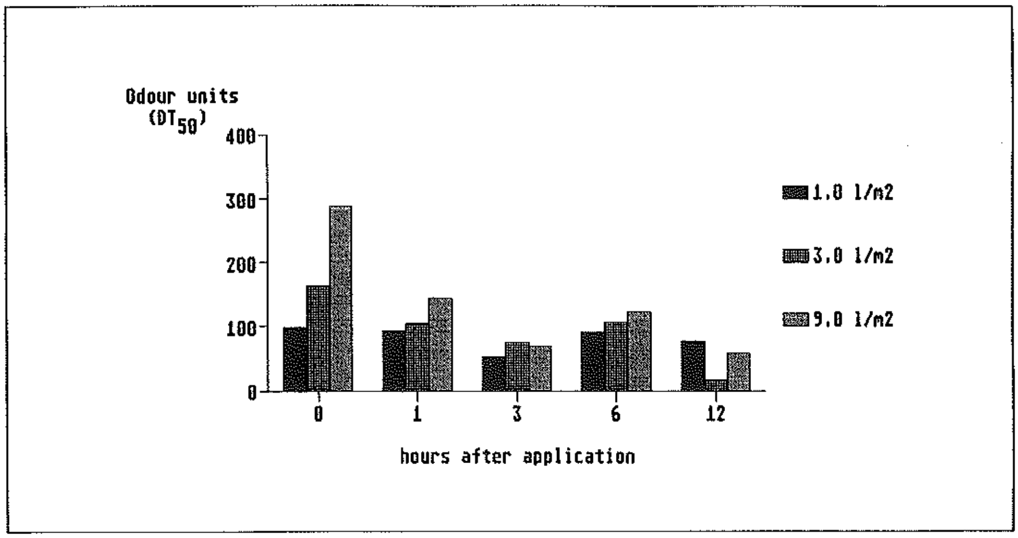

Figure 8. Odour emission from pig slurry at different rates of application. Experiment T2.

respectively. Subsequently, there was little effect of the rate of application on odour concentration. Total odour emission over 2 days increased with increasing rate of slurry application but not proportionally (table 7). Hence, there was a marked decrease in total emission per m^3 slurry applied with increasing application rate.

Table 7. Tunnel experiment 2: total odour emission.

Slurry	Pig	Pig	Cattle
Experimental period (days)	2	2	2
Application rate ($l.m^{-3}$)	1.0	3.0	9.0
Odour emission:			
$O.U.m^{-2}$ land	2775 x 10^3	2954 x 10^3	3949 x 10^3
$O.U.l^{-1}$ slurry applied	2775 x 10^3	985 x 10^3	439 x 10^3

5.3. Experiment T3: odour and ammonia emission from pig and cattle slurry.

Analyses of the pig and cattle slurry (table 8) used in this experiment were similar to those obtained in experiment T1. Similarly, results for ammonia emission (table 9) confirmed those from the earlier experiment, with ammonia loss being 44.3 and 10.5 kg NH_3-$N.ha^{-1}$ for pig and cattle slurry respectively or 2.6 and 0.6 kg NH_3-$N.m^{-3}$ slurry applied. Approximately 50% of the total loss occurred within the first 12 hours

Table 8. Tunnel experiment 3: slurry analyses.

Slurry	Pig	Cattle
Rate of application ($m^3.ha^{-1}$)	17	17
Total solids (%)	13.8	12.2
Total N (%)	0.84	0.44
NH_4–N (%)	0.43	0.15
P (%)	0.39	0.16
K (%)	0.40	0.27
pH	7.2	7.0
Total volatile fatty acids ($mg.l^{-1}$)	17680	5850
COD ($g.kg^{-1}$)	153	112

Table 9. Tunnel experiment 3: nitrogen applied and ammonia lost.

Slurry	Pig	Cattle
Experimental period (days)	3	3
Rates of application $m^3.ha^{-1}$	17	17
Nitrogen applied:		
kg NH_3–$N.ha^{-1}$	73.1	25.5
kg total $N.ha^{-1}$	142.8	74.8
Ammonia loss:		
kg NH_3–$N.ha^{-1}$	44.3	10.5
% of NH_4–N	60.4	41.1
% of total N	30.1	14.0
kg NH_3–$N.m^{-3}$ slurry applied	2.6	0.6

after application. Apart from the initial threshold value for pig slurry, the pattern of the odour emission (fig. 9) was as for experiment T1. Total odour emission (table 10) was again greater for cattle than for pig slurry.

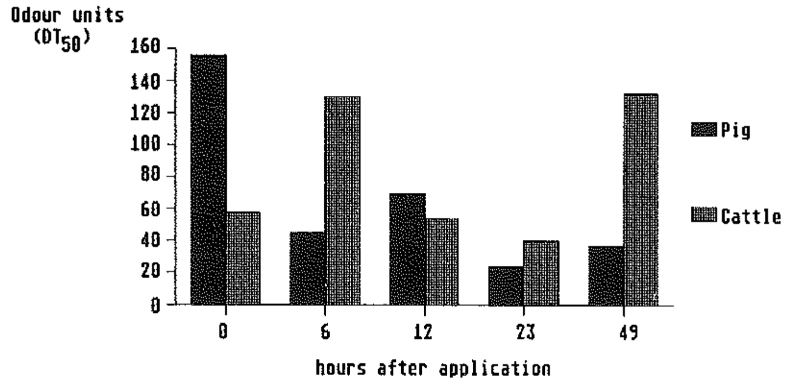

Figure 9. Odour emission from pig and cattle slurry. Experiment T3.

Table 10. Tunnel experiment 3: total odour emission.

Slurry	Pig	Cattle
Experimental period (days)	2	2
Application rate ($l.m^{-3}$)	1.7	1.7
Odour emission:		
$O.U.m^{-2}$ land	1661 x 10^3	977 x 10^3
$O.U.l^{-1}$ slurry applied	2778 x 10^3	1643 x 10^3

5.4. Experiment T4: odour and ammonia emission from different types of poultry waste.

The sources of the 4 types of poultry wastes used in this experiment are described in paragraph 4.2.3. The influence of the different types of management on waste composition is well illustrated in table 11. The two drier wastes, COVP 5 and COVP 8 had high total N contents with NH_4-N representing 19 and 30% respectively. The two slurries, COVP 9 and COVP 10, had lower total N contents but NH_4-N represented 53 and 55% respectively.

Table 11. Tunnel experiment 4: slurry analyses.

	COVP 5	COVP 8	COVP 9	COVP 10
Type of birds	Broilers	Layers	Layers	Layers
Manure/Slurry	litter droppings	air dried (belt)	slurry (belt)	slurry (open pit)
Rate of application ($m^3.ha^{-1}$)	6	6	10	10
Total solids (%)	75.0	61.0	17.5	26.0
NH_4–N (%)	0.57	1.07	0.51	0.76
Total N (%)	2.95	3.53	0.96	1.39
P (%)	1.43	1.67	0.49	0.92
K (%)	1.84	1.47	0.81	0.83
pH	8.3	6.9	8.5	9.1
Total VFA ($mg.l^{-1}$)	–	–	22900	–

Total ammonia loss (kg NH_3–$N.ha^{-1}$) was much greater from the slurries than from the drier materials (table 12). The highest loss occurring from COVP 10 was equivalent to 83% of the NH_4–N applied or 6.3 kg NH_4–$N.m^{-3}$ slurry applied. The smallest loss, 2.1 kg NH_3–$N.m^{-3}$ slurry applied, was from the broiler litter (COVP 5). Results from air dried droppings from layers (COVP 8) were similar. Air drying droppings reduced ammonia loss (kg NH_3–$N.m^{-3}$ slurry applied) by 38% compared with the conventional belt collection system.

Table 12. Tunnel experiment 4: nitrogen applied and ammonia lost.

	COVP 5	COVP 8	COVP 9	COVP 10
Type of birds	Broilers	Layers	Layers	Layers
Manure/Slurry	litter droppings	air dried (belt)	slurry (belt)	slurry (open pit)
Experimental period (days)	6	6	6	6
Rate of application ($m^3.ha^{-1}$)	6	6	10	10
Nitrogen applied:				
kg NH_4–$N.ha^{-1}$	34	64	51	76
kg total $N.ha^{-1}$	177	212	96	139
Ammonia loss:				
kg NH_3–$N.ha^{-1}$	12.7	13.8	36.7	63.1
% of total NH_4–N	37.4	21.4	72.0	83.1
% of total N	7.2	6.5	38.2	45.4
kg NH_3–$N.m^3$slurry applied	2.1	2.3	3.7	6.3

Figure 10 shows the cumulative ammonia emission with time for the four different wastes and illustrates the very high rates of emission which occurred shortly after the application of slurries especially COVP 10, compared with those from air dried droppings and broiler litter.

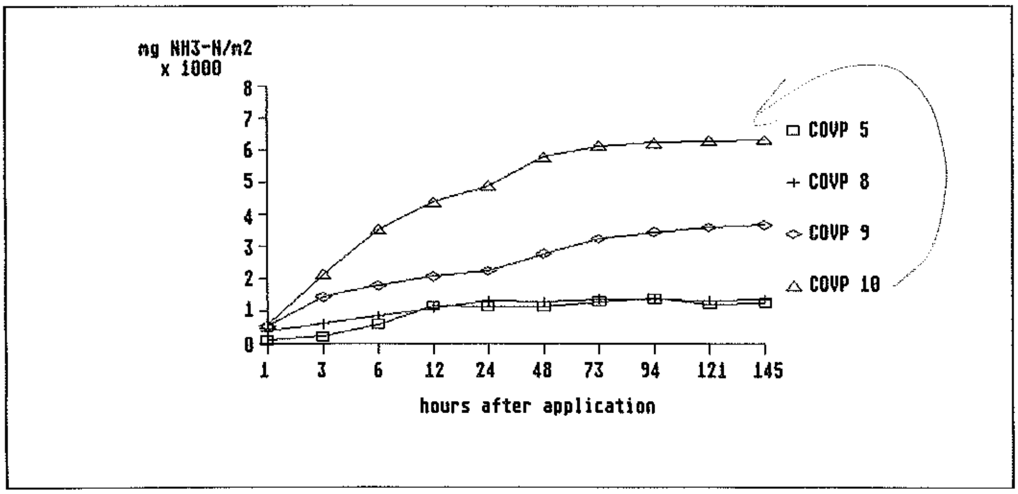

Figure 10. Accumulative ammonia emission from different poultry housing systems. Experiment T4.

Apart from the most dilute of the 2 slurries (COVP 9), maximum odour threshold values were not recorded until 24 hours after application (fig. 11). The lowest

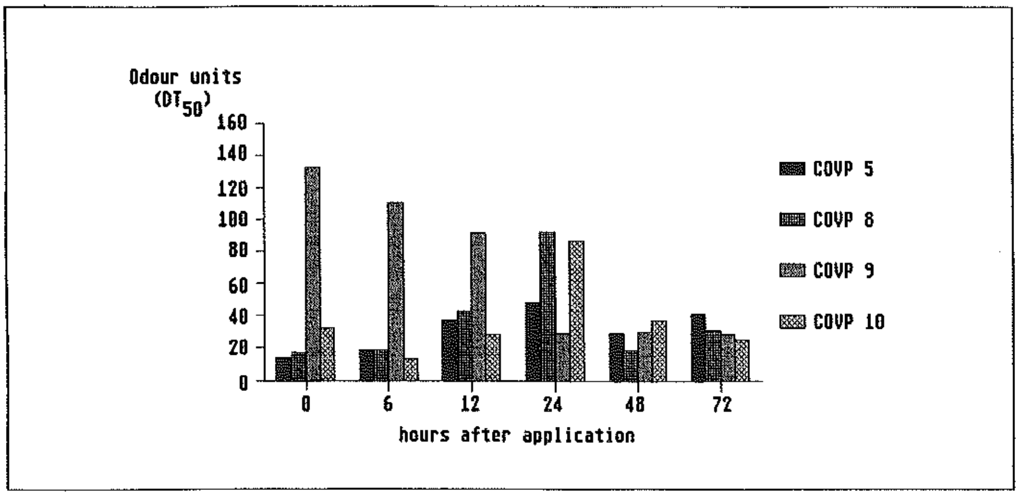

Figure 11. Odour emission from different poultry housing systems. Experiment T4.

maximum value was obtained from broiler litter (COVP 5) and the highest from slurry (table 13).

Table 13. Tunnel experiment 4: total odour emission.

	COVP 5	COVP 8	COVP 9	COVP 10
Type of birds	Broilers	Layers	Layers	Layers
Manure/Slurry	litter droppings	air dried (belt)	slurry (belt)	slurry (open pit)
Experimental period (days)	3	3	3	3
Application rate ($m^3.ha^{-1}$)	0.6	0.6	1.0	1.0
Odour emission:				
O.U.m^{-2} land	1869 x 10^3	2227 x 10^3	2647 x 10^3	2235 x 10^3
O.U.l^{-1}slurry applied	1121 x 10^3	1336 x 10^3	2647 x 10^3	2235 x 10^3

5.5. Experiments LR1–LR3 and M1–M3: odour and ammonia emission during and following application of cattle and pig slurry.

Analyses of the slurries used in these experiments are given in table 14 together with the rates of application. The cattle slurry was of similar composition to that used in the wind tunnel experiments. However, there were differences between the 2 pig slurries. The slurry used in LR2/M2 had a higher NH_4–N content and lower total solids content than that used in LR3/M3. Although the slurry for both experiments was obtained from the same store, slurry for LR2/M2 was pumped from the upper layers and that for LR3/M3 from the more settled material nearer the bottom of the

Table 14. Experiments LR1–LR3 and M1–M3: slurry analyses.

Experiment	LR1/M1	LR2/M2	LR3/M3
Slurry	Cattle	Pig	Pig
Rate of application ($m^3.ha^{-1}$)	15.0	15.6	14.0
Total solids (%)	10.3	13.6	18.7
Total N (%)	0.47	1.03	0.92
NH_4–N (%)	0.28	0.68	0.41
P (%)	0.12	0.31	0.40
K (%)	0.62	0.55	0.56
pH	7.6	8.2	7.3

pit. In both instances, the total solids content was higher than typical Dutch pig slurry.

5.5.1. Total ammonia emission during and following slurry application.

The total concentration of ammonia in air measured at 16 points on the Land Rover sampling frame during the 3 experiments are presented in tables 15–17. It was expected that the concentrations would be the greatest in the centre of the frame and decrease towards the periphery, but this was not always the case. This might be because the frame was wider than the width of the slurry spreader. Hence, after the first pass of the spreader, the outermost sampling points overlapped on the area already spread with slurry. Nevertheless, the mean concentration of ammonia in air was used to estimate emissions during application (table 18) as described in paragraph 2.5. In each experiment the amounts were very low but higher for pig than for cattle slurry. Ammonia losses following slurry application are given in table 19.

Direct comparison between the 3 experiments are difficult to make because of varying weather conditions. However, loss of ammonia from pig slurry was always greater than that from cattle slurry. Losses per m^3 slurry applied were always much greater following than those measured during spreading. For both cattle and pig slurry, loss during spreading represented 0.4–0.5% of the total ammonia (during and following application).

Table 15. Experiment LR1: concentrations of ammonia (NH_3–N.m^{3}air) at different points on the sampling frame.

			(16)			
			0.20			
		(13)	(14)	(15)		
		--	**0.76**	**0.07**		
	(8)	(9)	(10)	(11)	(12)	
	0.25	**0.51**	**0.46**	**0.17**	**0.41**	
(1)	(2)	(3)	(4)	(5)	(6)	(7)
0.86	**0.79**	**0.07**	**2.33**	**1.99**	**0.91**	**0.71**

( ) = sample number (see fig. 2). Mean of 16 samples = 0.70 NH_3–N.m^{-3} air

Table 16. Experiment LR2: concentrations of ammonia (NH_3–N m^3air) at different points on the sampling frame.

			(16)			
			1.04			
		(13)	(14)	(15)		
		1.07	**0.41**	--		
	(8)	(9)	(10)	(11)	(12)	
	3.16	**0.29**	**4.75**	**0.36**	**0.24**	
(1)	(2)	(3)	(4)	(5)	(6)	(7)
0.59	**1.05**	**0.50**	**0.35**	**0.90**	**1.04**	**0.88**

( ) = sample number (see fig. 2). Mean of 16 samples = 1.11 NH_3–N.m^{-3} air

Table 17. Experiment LR3: concentrations of ammonia (NH_3–N m^3air) at different points on the sampling frame.

			(16)			
			0.49			
		(13)	(14)	(15)		
		3.22	**0.74**	**3.00**		
	(8)	(9)	(10)	(11)	(12)	
	0.74	**0.62**	**0.60**	**0.12**	--	
(1)	(2)	(3)	(4)	(5)	(6)	(7)
0.71	**1.86**	**0.93**	**0.54**	**0.55**	**2.28**	**0.59**

( ) = sample number (see fig. 2). Mean of 16 samples = 1.13 NH_3–N.m^{-3} air

Table 18. Experiment LR1–3: ammonia loss during the application of pig and cattle slurry

Experiment	LR1	LR2	LR3
Slurry	Cattle	Pig	Pig
Rate of application ($m^3.ha^{-1}$)	15.0	15.6	14.0
Volume applied (m^3)	3.00	3.07	2.74
Mean wind speed ($m.s^{-1}$)	1.59	2.48	3.31
Driving speed ($m.s^{-1}$)	1.25	1.25	1.25
Spreading time (s)	142	137	128
Ammonia loss:			
kg NH_3–N.ha^{-1}	0.06	0.11	0.14
kg $NH_3.m^{-3}$ slurry applied	0.004	0.007	0.010

Table 19. Experiments M1–3: ammonia loss following the application of pig and cattle slurry.

Experiment	M1	M2	M3
Slurry	Cattle	Pig	Pig
Rate of application ($m^3 \cdot ha^{-1}$)	15.0	15.6	14.0
Experimental period (days)	3.2	3.1	2.8
Mean wind speed ($m.s^{-1}$)	1.90	1.66	2.80
Nitrogen applied:			
kg total $N.ha^{-1}$	70.5	160.7	128.8
kg NH_4–$N.ha^{-1}$	42.0	106.1	57.4
Ammonia loss:			
kg NH_3–$N.ha^{-1}$	16.6	25.5	35.3
% total N applied	23.5	15.9	27.4
% NH_4–N applied	39.5	24.0	61.5
kg $NH_3.m^{-3}$ slurry applied	1.12	1.53	2.52

5.5.2. Total odour emission during and following slurry application.

For cattle slurry (experiment LR1), odour concentration measured in samples collected at different points on the Land Rover frame ranged from 556 to 1460 odour units.m^{-3} air with a mean of 1059. No data were obtained for experiment LR2. For pig slurry in experiment LR3, the range was 942 to 3569 and the mean 2020 odour units.m^{-3} air. This compares well with similar experiments by van Harreveld (1981). As for ammonia emission, odour emission was calculated by multiplying the mean concentration by the volume of air flowing through the frame during spreading. The results are given in table 20 together with the total odour emission over the 2 days following application. The latter values were calculated by taking the mean rate of

Table 20. Experiments LR1–3 and M1–3: odour emission during application and for the two days following the application of cattle and pig slurries.

		Odour units m^{-3} slurry applied	
Experiment	Slurry type	during application	following application
LR1/M1	Cattle	5.7×10^6	2.6×10^9
LR2/M2	Pig	.–––	3.9×10^9
LR3/M3	Pig	17.2×10^6	8.4×10^9

emission (odour units.$m^{-2}.h^{-1}$) for 2 consecutive samples and multiplying by the number of hours in the intervening period. Extrapolating from odour units.m^{-2} land to volume of slurry enabled the total emission to be estimated in odour units.m^{-3} slurry applied and the emission during and following application to be compared (table 20). Odour emission during spreading represented about 0.2% of the total emission for both cattle and pig slurry. Both during and following application, odour emission was approximately 3 times greater for pig than for cattle slurry.

The pattern of NH_3 emission (kg NH_3–N.ha^{-}.h^{-1}) was similar for both pig slurries and, as illustrated in fig. 12 and 13, influenced by the changes in wind speed and air temperature that occurred during the course of the experiment. Higher wind speed and temperature during daylight periods tended to favour increased rates of NH_3 volatilisation especially during experiment M3

The odour threshold value during the first hour after application was about 400 in experiment M2 but 900 in experiment M3. Since the slurry for the later experiment was withdrawn from the lower part of the storage pit, the difference may be a reflection of the differences in composition or storage period of the two slurries. Although the rate of odour emission (odour units.$m^{-2}.h^{-1}$) was influenced by changes in wind speed as observed for NH_3 emission, higher mean wind speeds in experiment M3 resulted in more rapid decrease in threshold value and in rates of odour emission than in experiment M2. However, apart from the differences during the first hour of application, odour emission was similar in both experiments (table 21).

Table 21. Odour emission during and after spreading.

Period		Odour emission (O.U. $s^{-1}.m^{-3}$ slurry applied)	
		LR1/M1	LR3/M3
During spreading		39.9×10^3	134.6×10^3
0–1	hour(s) after spreading	25.5×10^3	31.4×10^3
6–7	,,	15.5×10^3	28.7×10^3
12–13	,,	2.0×10^3	14.9×10^3
24–25	,,	7.6×10^3	37.8×10^3
36–37	,,	---	6.7×10^3
48–49	,,	30.7×10^3	19.7×10^3
62–63	,,	---	2.6×10^3

The results for cattle slurry (experiment M1) are summarised in fig. 14. As for the wind tunnel experiments, the major differences from pig slurry were lower than rates of NH_3 emissions and lower odour threshold levels during the first hour after application. The maximum threshold value recorded was less then 200. Higher rainfall during the course of this experiment may have depressed ammonia volatilisation.

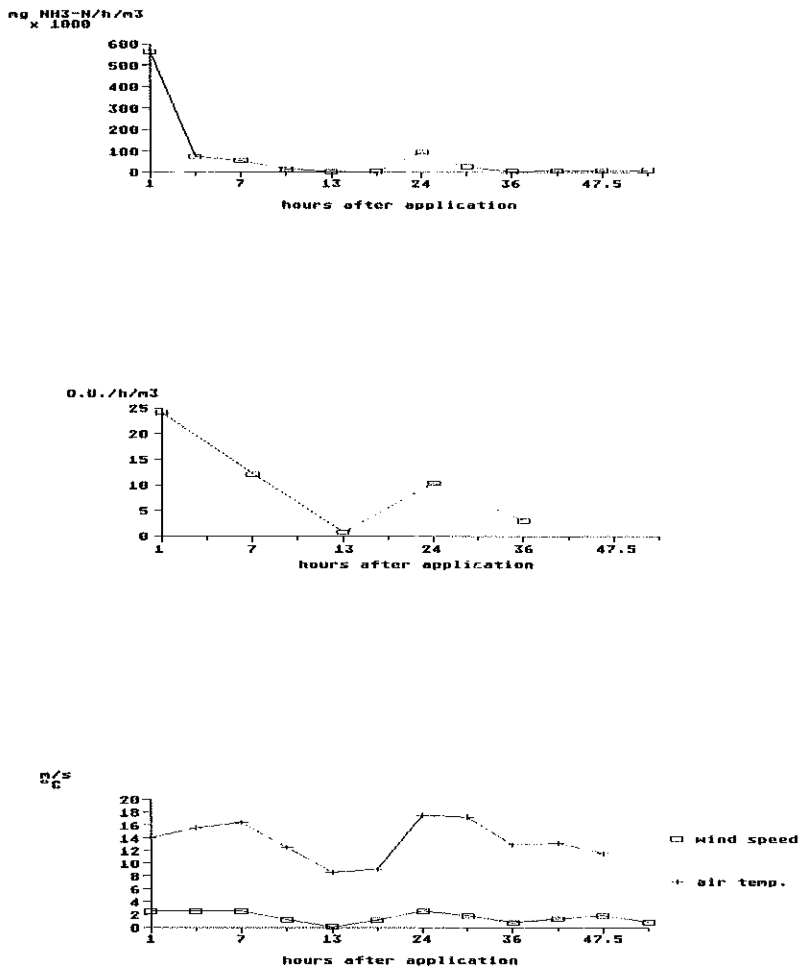

Figure 12. Emission of pig slurry. Experiment M2.

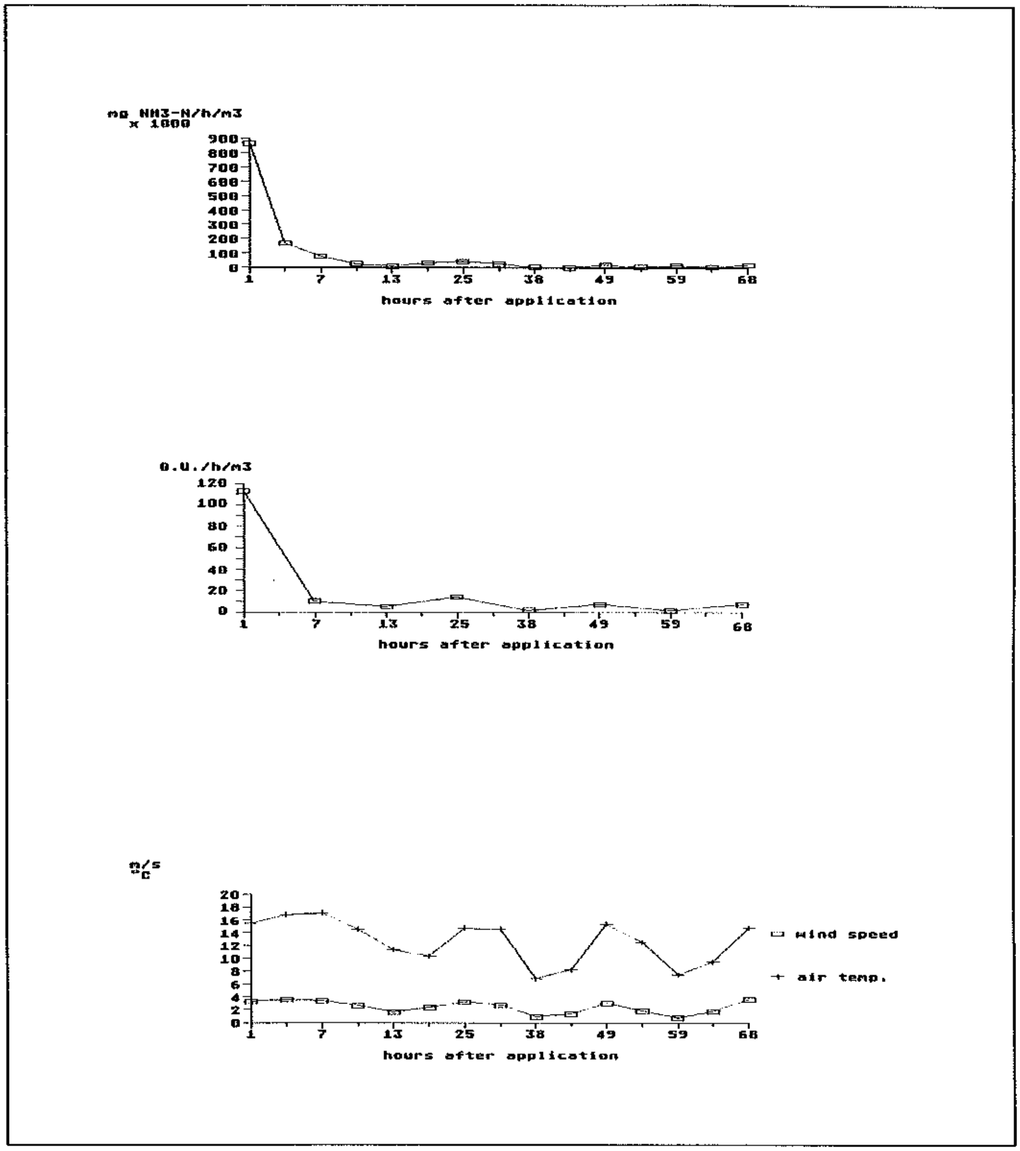

Figure 13. Emission from pig slurry. Experiment M3.

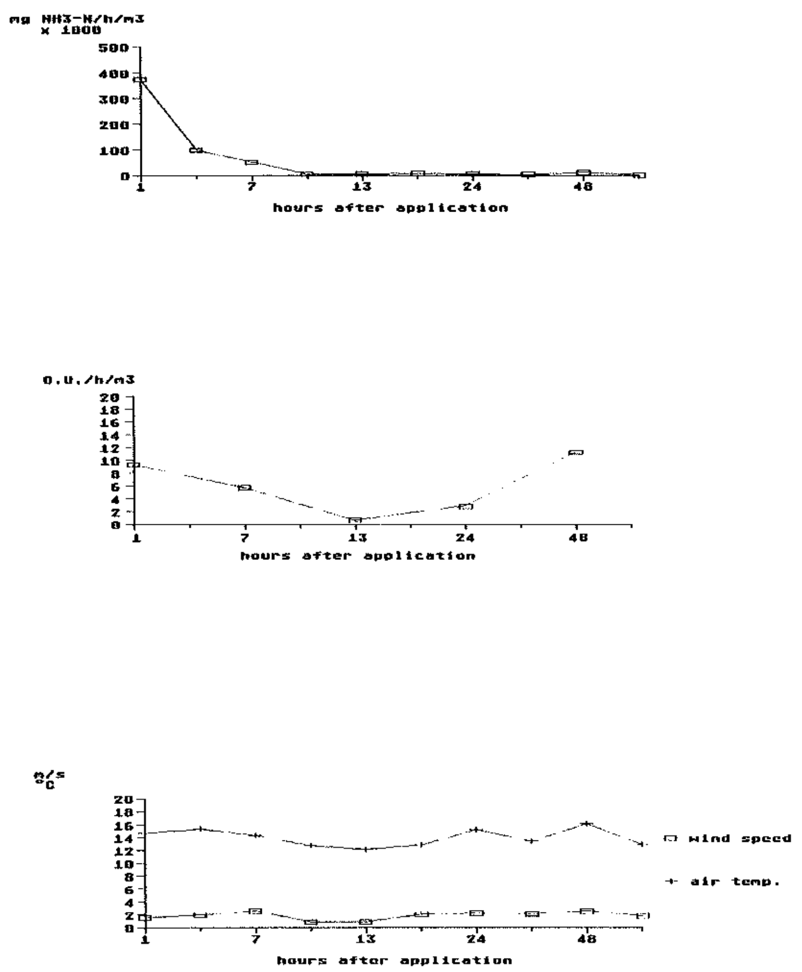

Figure 14. Emission from cattle slurry. Experiment M1.

6. Conclusions.

A summary of ammonia and odour emission per m^3 slurry or manure applied is given in table 22, application rates being 10–17 $m^3.ha^{-1}$ for slurry and for 6 $m^3.ha^{-1}$ for manure. Comparative data from wind tunnel experiments indicated that the highest loss of ammonia occurred from poultry slurry, and the lowest from cattle slurry. Odour emission was greater from both poultry slurry and manure than from cattle or pig slurry. Although results from the micrometeorological experiments were influenced by the ambient weather conditions, they confirm the greater loss of ammonia from pig slurry compared with that from cattle slurry, but suggest that odour emissions may be higher than that measured from the wind tunnels. Ammonia and odour emission was relatively low during application and represented less than 1% of the total emissions over 3 days.

There were marked differences in the pattern of odour emission from the different wastes following the application. During the first hour after application, emission from pig slurry was much greater than from other wastes used in the experiments. Similarly, very high rates of ammonia emission occurred from pig slurry shortly after application. The method of collection and management of poultry wastes markedly influenced the pattern of odour and ammonia emission. For drier manures (air–dried droppings or broiler litter), maxima were not recorded until 12–24 hours after application.

Odour and ammonia emission increased with increasing rate of pig slurry application but the relationship did not appear linear. Total emission per m^3 slurry applied was lowest for the highest rate of application.

As to be expected, weather conditions influenced emissions. Higher wind speeds and temperatures during the day increased emission compared to night conditions.

With respect to loss of fertiliser value, ammonia emission following application was equivalent to 68, 56, 41 and 29% of the NH_4–N applied in poultry, pig and cattle slurry and poultry manure respectively.

Increase in ammonia and odour concentrations in the ambient air were recorded when weather conditions favoured spreading of slurry by farmers in the vicinity of the experimental site.

Table 22. Mean ammonia and odour emission from slurries and manures applied to grassland.

Manure/slurry	Cattle	Pig	Poultry
Wind tunnel			
Number of experiments	2	3	2
Emission (m^{-3} slurry applied)			
kg NH_3–N	0.60	2.60	4.20
Odour units.m^{-3} air	1.84×10^9	1.80×10^9	2.53×10^9
Emission ($s^{-1}.m^{-3}$ slurry applied)			
kg NH_3–N	1.70	7.50	8.90
Odour units.m^{-3} air	8.50×10^3	9.10×10^3	9.80×10^3
Land Rover			
Number of experiments	1	1	
Emission (m^{-3} slurry applied)			
kg NH_3–N	0.004	0.008	
Odour units.m^{-3} air	5.70×10^6	17.50×10^6	
Emission ($s^{-1}.m^{-3}$ slurry applied)			
kg NH_3–N	28.20	64.60	
Odour units.m^{-3} air	3.80×10^4	13.7×10^4	
Micro meteorological			
Number of experiments	1	2	
Emission (m^{-3} slurry applied)			
kg NH_3–N	1.12	2.03	
Odour units.m^{-3} air	2.60×10^9	6.15×10^9	
Emission ($s^{-1}.m^{-3}$ slurry applied)			
kg NH_3–N	4.10	8.10	
Odour units.m^{-3} air	1.40×10^4	2.50×10^4	

7. Recommendations for future collaboration.

The main priorities for future work where there is benefit in combining Anglo-Dutch resources are:

–To establish the influence of method of slurry application on odour emission.

Although the preliminary experiments in the Netherlands indicate that ammonia and odour emission during spreading represented a very small proportion of the total emission, this requires further verification. In addition, the very high but short-lived odour emission during spreading operations may be less acceptable to the public than the lower but more persistent rates of emission which occur after spreading. Joint experiments in the United Kingdom would enable comparative data to be obtained for 5-6 different types of slurry applicators during a 4 week period. It is proposed that the experiments should be conducted on land at AFRC-Engineering in April 1988.

–To validate and refine the micrometeorological method for quantitative odour collection.

For ammonia emission, this method involves the measurement of gas concentrations on 5-6 different heights above an experimental area. Because of the limited number of olfactometric measurements possible per day, a modified version of a method is used in odour measurements. The modified method, which is based on meteorological theory, requires measurement of gas or odour concentration and wind speed at one pre-determined height. Comparative data for the two methods have been obtained for ammonia but not for odours.

Refinement of sampling procedures may be advantageous. Theory indicates that sampling of odorous air at a rate proportional to wind speed may improve accuracy of measurement.

Identification and resolving major source of variation in collection and measurement of odours would also contribute to better measurements.

–To evaluate methods for reducing ammonia and odour emission following application.

Methods like cultivations, injection, modifying composition of slurries (e.g. dilution) are associated with reduction of emissions arising from landspreading.

–To assess influence of slurry and livestock management on emissions from landspreading.

Factors to include method of slurry storage prior to application and types of livestock management.

–To investigate dispersion of odours.
For the next few years land on the new polders offers the advantage of a sufficiently large, homogeneous area with minimal background levels of odour and ammonia emissions. This is a unique situation which cannot be found in the U.K. It is therefore proposed that recommendations 2–5 are being undertaken during joint experiments in the Netherlands in 1988

8. Acknowledgements.

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