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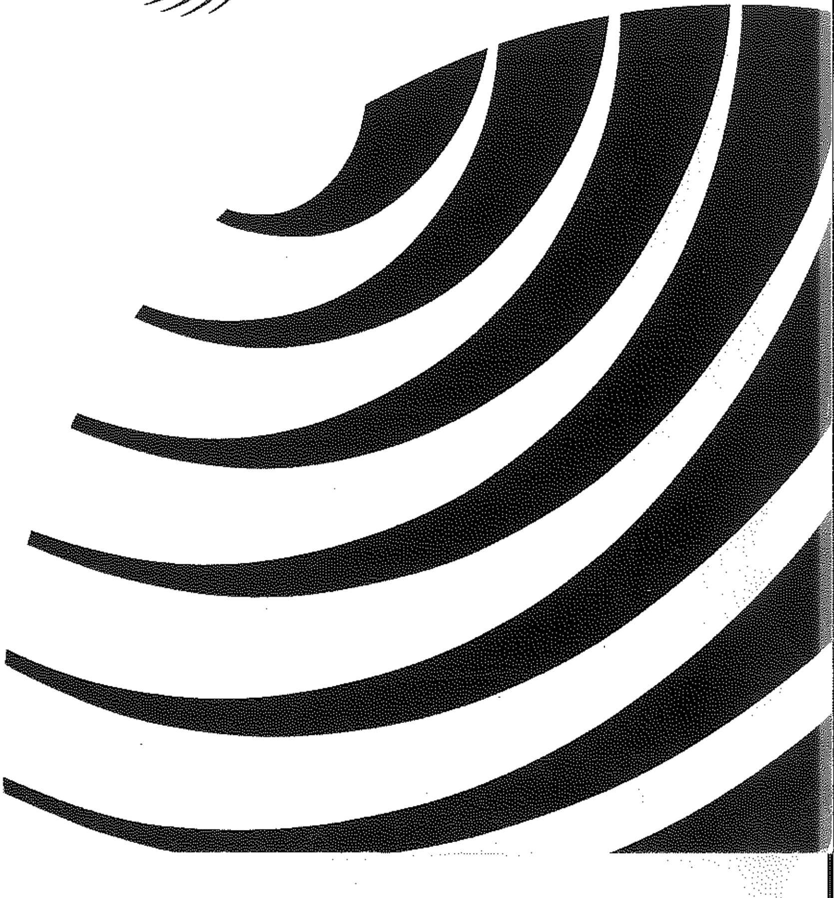

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Preface

In September 1979 the Minister of Agriculture, Fischeries and Food of the United Kingdom and the Minister of Agriculture and Fisheries in The Netherlands agreed to pursue a program of collaboration in agricultural research. As a result of further discussions it was agreed that one of the topics suitable for further collaboration would be Recycling of Farm Wastes. Priority aspects were considered to be treatment of farm wastes and reduction of odours emanating from animal slurries. As coordinators for this subject were nominated Mr V.C. Nielsen from the Agricultural Development and Advisory Service (ADAS) at Reading UK and Ir. J.H. Voorburg from Rijks Agrarische Afvalwaterdienst (RAAD) at Arnhem (later IMAG-DLO).
As there was no budget available the cooperation started with exchange of experiences and comparison of research results.

In 1986 the cooperation became more active. From a combined project on the measurement of odour emissions, a small budget was made available to introduce the experience of experts from the Institute of Agricultural Engineering at Wageningen to the UK. This proved to be a very effective way in mastering problems associated with measuring volatile emissions.
The next year, experts from the AFRC Institute for Grassland and Animal Production at Hurley, and the AFRC Institute of Engineering Research at Silsoe were invited to come to The Netherlands for combined research on the ammonia emissions from land spreading of animal wastes.

The present report contains the results of a combined research programme on emissions from land spreading animal wastes on arable land in 1988. Not only emissions were studied but abatement was also included in this programme.
The outcome of the experiments contains useful information for day to day farming practice. Furthermore it demonstrates the extent to which good international cooperation can reach in agricultural science.

Ir. A.A. Jongebreur
director

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Summary

Emissions of odour and ammonia from land spreading animal wastes are well known phenomena. For various reasons, national policies in the north western part of Europe are focused on decreasing both types of air pollution. In The Netherlands, for instance, emphasis is on ammonia while in the UK much attention is paid to the reduction of odours.

Odour and ammonia emissions occurring after land spreading of piggery wastes can be abated by tilling after spreading. Since it reduces the slurry surface exposed to air. Also, it increases the contact of NH_4^+-ions with soil colloids, thus reducing ammonia emissions even further.

Since a wide range of tillage techniques exists, each with specific advantages and disadvantages, research was carried out into the effectiveness of common equipment available on arable farms e.g. ploughing, harrowing and cultivation with tines. During a three week period, experiments were conducted on clay soil incorporating slurry immediately after application, three hours after application and six hours after application. The effect on the emission was measured using micrometeorological and wind tunnel techniques.
Furthermore, preliminary experiments were conducted on sandy soils using wind tunnels only. The scope of this work was much the same as the experiments on clay soil.

In addition to reducing emissions after spreading, it is also possible to apply animal wastes with lower potentials for odour and ammonia loss. Reduced potentials in pig slurry can be achieved by various types of treatment. During a one week experimental period, investigations were made into the emission of ammonia emanating from pig slurries subjected to different storage regimes as well as the emission from faeces and urine produced by an in-house belt separation system installed in a piggery.

With respect to the results obtained by incorporating slurry after spreading, the following was established. In comparison with the control, any delay of incorporation results in a higher total emission. The longer the delay, the more the emission. These results were consistent throughout all experiments on clay and sandy soils. Furthermore, incorporation of slurry by ploughing gave better results on clay soils than incorporation by using a rotary harrow. Much the same applied to sandy soils for ploughing and rotavating. Using a cultivator was least effective in reducing emissions on clay and sandy soils.

As far as odour emissions are concerned, only direct incorporation on clay soil resulted in substantial reductions. Delaying incorporation did not effect the emission level significantly. However, using different machinery showed distinct differences and ploughing was always most effective for odour abatement.

As far as slurry treatment is concerned, no substantial difference in ammonia emission was observed between a control and slurry which has been frequently removed from the piggery. On the other hand, installation of an in-house belt separator may contribute to the reduction of ammonia emissions after landspreading. Losses during spreading of urine were less than 20% of those from a control whilst losses during spreading of faeces were of the same order as those from untreated pig slurry.

1 Introduction

This report describes the third series of joint experiments conducted under the auspices of the Anglo-Dutch Agreement on Farm Wastes, 1980. The first series was conducted in Wageningen in June 1987, and was concerned with comparing odour and ammonia emission following application of different types of livestock wastes to grassland. The results of these experiments were reported by Pain and Klarenbeek (1988), Pain et al. (1989) and Lockyer et al. (1989). The second series of experiments were conducted at the AFRC Institute of Engineering Research (AFRC Engineering) at Silsoe in the UK during April 1988. The aim was to compare emissions during application of pig slurry to grassland using different types of spreading machinery. These experiments were reported by Phillips et al. (1990).

Initially, Anglo-Dutch collaboration provided opportunity to exchange technology, methods and ideas. UK workers have gained much from the Dutch expertise in olfactometry and have employed equipment and methods developed at the DLO Institute of Agricultural Engineering (IMAG-DLO) in the measurement of emissions during slurry spreading. The Dutch have benefitted from the micrometeorological and wind tunnel methods used by the AFRC Institute for Grassland and Environmental Research (AFRC-IGER) in the measurement of ammonia and odour emissions in the field and have subsequently constructed or purchased similar equipment. Continued collaboration is invaluable because it allows trained staff and equipment from both countries to be combined and to undertake larger scale, more productive experiments than would be feasible with the resources available to each individual organization involved.

The current series of experiments were conducted on arable land, mainly on the new polder in Flevoland, and aimed to investigate methods for reducing emissions of ammonia and odour by incorporating pig slurry into the soil. A further experiment was conducted to determine the influence of the method of waste management within the piggery on subsequent emissions after application to land. All the experiments were conducted between August (week 35) and October (week 40) 1988.

2 Materials and methods

2.1 Field techniques

In the field, three methods were used in the sampling of air for ammonia and odours. All three methods are described in detail by Pain and Klarenbeek (1988).

Two wind tunnel systems were used, each comprising four tunnels. One was identical to that from AFRC-IGER (Lockyer, 1984) described in the earlier report and the other, although based on the same tunnel design, was from IMAG-DLO and employed different equipment for controlling airflows and logging data. Wind speed through the tunnels was controlled to approximately 1 $m \cdot s^{-1}$ during experiments in the measurement of emissions from 1 m^2 areas of land. Ammonia concentration in the air entering and leaving the tunnels was sampled continuously by using absorption flasks containing orthophosphoric acid. The absorption flasks were changed after pre-determined periods, normally 1, 3, 6, 12, 24, 36, and 48 hours after slurry application and finally removed at 96 hours, to determine the cumulative ammonia loss and rate of ammonia loss. The rate of ammonia loss during the sampling period was calculated from:

$$F = \left(\frac{x_2 \cdot y_3}{y_2} - \frac{x_1 \cdot y_3}{y_1}\right) \cdot 10^{-6} \qquad [1]$$

where F = rate of ammonia loss (kg NH_3-$N \cdot h^{-1}$),
x_1 = ammonium contained in inlet absorption flask (mg NH_4^+-N),
x_2 = ammonium contained in outlet absorption flask (mg NH_4^+-N),
y_1 = volume of air through the inlet absorption flask (m^3),
y_2 = volume of air through the outlet absorption flask (m^3),
y_3 = flowrate of air through the tunnel ($m^3 \cdot h^{-1}$).

Because the tunnel area was 1 m^2, the loss (kg NH_3-$N \cdot m^{-2} \cdot h^{-1}$) has the same value as F in equation 1. The total loss during a sampling period was calculated by multiplying the ammonia loss per m^2 by the number of hours in a period. Summing the loss during each period gave the total ammonia lost over 96 hours for each wind tunnel (kg NH_3-$N \cdot m^{-2}$).

For odour collection, a Metal Bellows pump (MB 158E) was used to draw air through a length of FEP-tubing fixed within the tunnel upstream of the fan and to inflate 60 l Teflon-FEP bags in 5-10 minutes. Normally, samples were collected immediately after slurry application and then at pre-determined times up to 48 hours. The rate of odour emission was then calculated from the product of the odour concentrations (odour units$\cdot m^{-3}$ air) and the air flow through the tunnel. This allowed the results to be expressed as rate of emission (e.g. odour units$\cdot s^{-1}$) or as total emission over a period of time. The odour emission for the periods between samples was calculated from the product of the mean odour concentration of two successive samples and the appropriate period of time. Summing the total emission for each period gave the total odour emission over 48 hours.

Emission from circular plots with an area of 1590 m^2 were determined by micrometeorological techniques as described in the previous report. A mass balance method (Denmead, 1983) was used for ammonia emissions which involved the measurement of ammonia concentration in air and of wind speeds at five or six heights above the experimental plots. Background ammonia concentrations were measured upwind of the plots. As for wind tunnel experiments, ammonia absorption flasks were changed after pre-determined periods and the rate of ammonia loss ($kg\ NH_3\text{-}N \cdot ha^{-1} \cdot day^{-1}$) for each period calculated by means of programs installed on both the AFRC-IGER and IMAG-DLO VAX computers. This also enabled the total ammonia loss ($kg\ NH_3\text{-}N \cdot h^{-1} \cdot m^{-3}$ slurry applied) over the duration of the experiment to be calculated.

A simpler method (Wilson et al., 1982) requiring measurements of odour concentration and windspeed at one height (Z_{inst}) was used for odour. Air samples were collected into 60 l FEP-Teflon bags commercially available from Polyfluor at Oosterhout, NL. Samples were taken over 30 minute periods immediately after slurry had been spread and at intervals thereafter. Metal Bellows pumps and PTFE sampling tubing were used. The rate of odour emission was calculated from:

$$F = \bar{s} \cdot \bar{c} / \left(\frac{\overline{s\,c}}{F} \right) \qquad [2]$$

where F = odour loss (odour units $\cdot s^{-1} \cdot m^{-2}$),
$\bar{s}$ = windspeed at height Z_{inst} ($m \cdot s^{-1}$),
$\bar{c}$ = odour concentration at height Z_{inst} (odour units $\cdot m^{-3}$ air),
$\left(\frac{\overline{s\,c}}{F} \right)$ = ratio from Wilson et al. (1982).

This gave the rate of odour emission for each 30 minute sampling period. By taking the mean of two consecutive measurements and multiplying by the appropriate time factor, it was possible to estimate the odour emissions for periods between samples and, by summing these, the total odour emission over the duration of the experiment.

A method similar to that described by Pain and Klarenbeek (1988) was used to measure emissions during slurry spreading. A Land Rover equipped with a sampling frame for ammonia and odour was driven behind the spreading machine, exactly downwind of it, at the same speed, and at the minimum distance which ensured that the samplers were not contaminated by droplets of slurry. Ammonia emission was calculated by dividing the frame into 4 horizontal bands measuring 10 m × 1.45 m (bottom, nearest the ground), 7 m × 1.65, 4 m × 1.65 m and 2 m × 1.30 m (top of frame). Summing the rate of emission for each of the four bands gave the total rate of emission for the spreading operation. The emission for each band was calculated from the mean concentration of ammonia and the air volume flowing through the band during spreading. The air volume for each band was calculated from the product of its cross-sectional area and wind speed at the mean height of the band plus ground speed of spreader. The latter was 2.5 $km \cdot h^{-1}$. Wind speed for each spreading operation was derived from the mast supporting five anemometers at different heights and used to provide data for calculating emissions after slurry applications. A regression line of wind speed on height was plotted to determine the wind speed for each band.
A similar procedure was used in calculating odour emission. Since fewer sampling points were used than for ammonia, the frame was sub-divided into 3 bands only, measuring 10 m × 1.45 m (bottom), 5.5 m × 2.65 m and 3 m × 1.95 m (top).

2.2 Analysis

Ammonia concentration was determined by ion chromatography at the IMAG-DLO environmental research laboratory in Arnhem.

Odour concentration (odour units$\cdot$m^{-3} air) was determined by four similar dynamic dilution olfactometers of the forced-choice type. A panel of eight members was used and, for each sample, five dilutions were presented to each panel member three times. The mean 50% threshold value was calculated from linear regression of correct panel responses using a log-normal transformation.

2.3 Sites

Most of the experiments were conducted on a clay soil under wet conditions on the new polder in Flevoland on an area from which oilseed rape had been recently harvested. The soil is classified as a young marine type clay with 25-30% silt and 3.75-4.25% organic matter. The $CaCO_3$-content was 8.2%.

Preliminary experiments were also conducted at IMAG-DLO on a light, sandy soil that had been recently cultivated.

2.4 Treatments

2.4.1 Introduction

A summary of the treatments used in the experiments on the polder and at IMAG-DLO is presented in table 1.

Table 1 Summary of experiments conducted between week 35 and 40, 1988

Expt	Week	Method	Location	Treatments
M1	35	Mast	Polder	Incorporation by plough, rotary harrow or rigid tines immediately after application of pig slurry.
M2	36	,,	,,	As M1 but incorporation three hours after application.
M3	38	,,	,,	As M2.
M4	37	,,	,,	As M1 but incorporation six hours after application.
M5	40	,,	,,	Four piggery wastes viz. liquid and solid fractions produced by an in-house belt separator; slurry stored for entire fattening period in pit beneath house; slurry removed from fattening house weekly and stored in enclosed tank.
T1	35	Wind tunnel	Polder	As M1.
T2	36	,,	,,	As M2.
T3	37	,,	,,	As M4.
T4	35	,,	IMAG	Incorporation by plough, rotavator or spring tines immediately after application.
T5	38/39	,,	,,	Repeat of T4.
T6	36	,,	,,	As T4 but incorporation three hours after application.
T7	38	,,	,,	Repeat of T6
T8	37	,,	,,	As T4 but incorporation six hours after application.

2.4.2 Method of tillage to incorporate surface spread slurry

Ammonia emission occurs when slurry is exposed to the air. Tilling after spreading slurry will reduce exposed slurry surfaces and increase contact of NH_4^+-ions with the soil colloids. Direct injection of slurry into the soil has proved to result in minimal emission since, assuming the machinery is operated skilfully, the slurry is completely buried. However, injection is not suitable for all soil conditions, fits less well into the cultivation program than other methods and may be more costly. A range of alternative techniques is available for burying or mixing slurry into soil on bare arable land. The most suitable technique will depend upon the soil type and the time of year i.e. before or after the growing season.

An obvious choice of implement is a plough since this should completely bury the slurry beneath the soil. It is important that the slurry is not buried too deeply since this may place the plant nutrients out of reach of following crop and, in some circumstances, could increase the potential for loss of nitrogen through nitrate leaching. Another consideration to be taken into account in the choice of implement is its work rate or capacity. A high proportion of the total ammonia loss occurs within a few hours of slurry application. The implement should, therefore, have a sufficiently high capacity for the tillage to be completed as soon as possible after spreading.

As an alternative to the plough, there are other tillage implements that operate more in the upper layers and mix slurry into the soil. Depending on the intensity of the mixing, the use of these types of implement will leave a proportion of the slurry still exposed to the air. However, they have the advantage of retaining the plant nutrients in the upper soil layers and, furthermore, the enlargement of the interfacial area between slurry and soil particles may help to 'bind' the slurry and so reduce emissions. More research is needed to test the latter possibility.

In summary, the following factors will influence the choice of tillage technique:
- minimization of exposure of slurry to the air by mixing or burying,
- the placement of plant nutrients in slurry, their availability to a following crop is an important consideration,
- sufficiently high capacity of the tillage implement,
- economics,
- compatibility with conventional tillage procedures.

In the current experiments, these factors led to the choice of the following implements on clay and sandy soils:

for clay soil (stubble)
- mouldboard stubble plough (ca. 150 mm deep),
- rigid tine cultivator,
- rotary harrow (with horizontal rotary elements driven by PTO).

For sandy soil (bare)
- mouldboard plough (ca. 300 mm deep),
- spring tine cultivator with lightweight roller,
- rotavator (with PTO driven blades).

Experiments M1 to M4 each comprised four circular plots to which pig slurry was applied at a rate between 60 and 65 $m^3 \cdot ha^{-1}$. After application the slurry was incorporated into the soil by one of the three methods, or left on the soil surface to provide a control. The incorporation was carried out immediately after application (expt M1), after a three hour delay (expt M2 and M3) or after a six hours delay (expt M4). Experiment M2 was repeated because heavy rain fell whilst the slurry was being spread in week 36 and it was thought that this may have influenced the rates of emissions of both ammonia and odour. In all these experiments, the slurry from a commercial pig fattening house was spread by a contractor using a conventional, tractor-drawn vacuum tanker.

Experiments T1 to T4 included the same treatments as M1 to M4 except that slurry was applied to smaller areas with watering cans. Experiments T5 to T8 were designed to provide information from a lighter, sandy soil. The treatments were similar to those on the polder except that the pig slurry was obtained from a 4 m^3 capacity experimental storage tank at IMAG-DLO, spring tines were used instead of rigid tines and a rotary cultivator instead of a rotary harrow. Ammonia emission only was measured.

2.4.3 Method of waste management in the piggery

Experiment M5 was designed to determine the influence of different methods of waste management on ammonia and odour emission. The wastes were collected from the Pig Experimental Station at Rosmalen. Liquids (primarily urine) and solids (primarily faeces) were obtained from a fattening house in which the droppings were separated within the piggery by a woven mesh belt fitted beneath the pens. Furthermore two types of slurry both from a pig fattening house were used. Slurry 1 was stored throughout the fattening period in an open pit beneath the slatted floor whereas slurry 2 was removed weekly and stored in an enclosed tank outside the building. The slurries were spread on land as described for the earlier experiments and the solid fraction by a rear discharge muck spreader.

2.5 Meteorological data

Wind speed data were collected on the experimental site on the polder. Rainfall and temperature data were obtained from the weather station at Lelystad.

3 Results

3.1 Method and time of slurry incorporation; micrometeorological experiments

3.1.1 Slurry analyses

Analyses of representative samples of the pig slurries used in experiments M1 to M4 are presented in table 2 together with the rates of application. The slurry used for experiment M3 was obtained from a different source to that for the other three experiments and contained less nitrogen but more total solids. For all four slurries, the ammonium-N content represented between 60 to 70% of the total N and the P, K contents and pH were similar.

Table 2 Experiments M1-M4. Slurry analyses and rates of application

		Experiment			
		M1	M2	M3	M4
NH_4^+-N	[$mg \cdot l^{-1}$]	5520	5960	4470	5740
Total N	[$mg \cdot l^{-1}$]	7770	9540	6770	8655
Total P	[$mg \cdot l^{-1}$]	1990	1880	2010	1935
Total K	[$mg \cdot l^{-1}$]	4410	4260	4420	4335
Total solids	[%]	9.0	8.4	10.9	8.8
pH		7.5	7.4	7.3	7.5
Volume applied	[$m^3 \cdot ha^{-1}$]	64	62	64	61
Rate of application:	[kg NH_4^+-N $\cdot ha^{-1}$]	355.4	368.8	287.3	350.1
	[kg $N_{tot} \cdot ha^{-1}$]	500.3	590.2	435.9	527.9

3.1.2 Ammonia emission following spreading

The total ammonia losses over 96 hours are given in table 3. For the unincorporated controls, ammonia loss ranged from 1.37 to 3.21 kg NH_3-N $\cdot m^{-3}$ slurry applied which was equivalent to 23.0 to 58.2% of the NH_4^+-N applied. These results are of a similar order to those recorded for pig slurry by Pain et al. (1989). The differences between the experiments are likely to be due, at least in part, to experimental error but are also a reflection of different soil and weather conditions (table 4).

Table 3 Experiments M1-M4. Total ammonia loss over 96 h after application of pig slurry

Expt	Incorporation		Ammonia loss over 96 h			
	method	time [h]	total [kg N·m^{-3} slurry]	% of NH_4^+-N applied	% of total-N applied	% reduction compared with control
M1	Plough	0	0.32	5.9	4.2	90
	Rotary harrow	0	0.70	12.9	9.2	78
	Tines	0	1.93	35.0	24.9	40
	Control	0	3.21	58.2	41.3	–
M2	Plough	3	0.45	7.4	4.6	68
	Rotary harrow	3	0.62	10.3	6.4	55
	Tines	3	0.92	15.4	9.6	33
	Control	3	1.37	23.0	14.3	–
M3	Plough	3	0.47	10.5	6.9	78
	Rotary harrow	3	0.90	20.2	13.3	58
	Tines	3	1.36	30.4	20.0	37
	Control	3	2.17	48.5	31.9	–
M4	Plough	6	0.78	13.5	9.0	54
	Rotary harrow	6	0.96	16.7	11.0	43
	Tines	6	1.11	19.3	12.8	34
	Control	6	1.67	29.1	19.3	–

Table 4 Meteorological data for experiments M1 to M4. Means for period of experiment

Expt	Wind speed*) [m·s^{-1}]			Air temp [°C]			Rainfall [mm]
	mean	max	min	mean	max	min	total
M1	3.61	6.90	0.97	15.0	17.6	12.3	19.6
M2	2.02	4.18	0.38	15.8	19.8	11.8	2.1
M3	1.96	–	–	14.0	15.8	12.3	3.6
M4	3.80	6.93	0.89	14.2	15.5	12.3	22.5

*) Measured at height Z_{inst} [approx. 1 m above ground level]

The relative effectiveness of the three methods of incorporation in reducing ammonia emission was consistent throughout the experiments. The plough was always the most effective, followed by the rotary harrow and the tines. Since the experiments were separated in time, soil and weather conditions varied. It is therefore more difficult to make valid comparisons between the emission from unincorporated slurry in different experimental periods. However, to achieve 50% emission reduction, ploughing could be delayed until six hours after spreading slurry or a rotary harrow could be used up to three hours after spreading. The tines did not reduce emission by more than 40% even when used immediately after spreading. Unsatisfactory operation of the tines in experiment M1, which resulted in excessive clod production may explain this poor result.

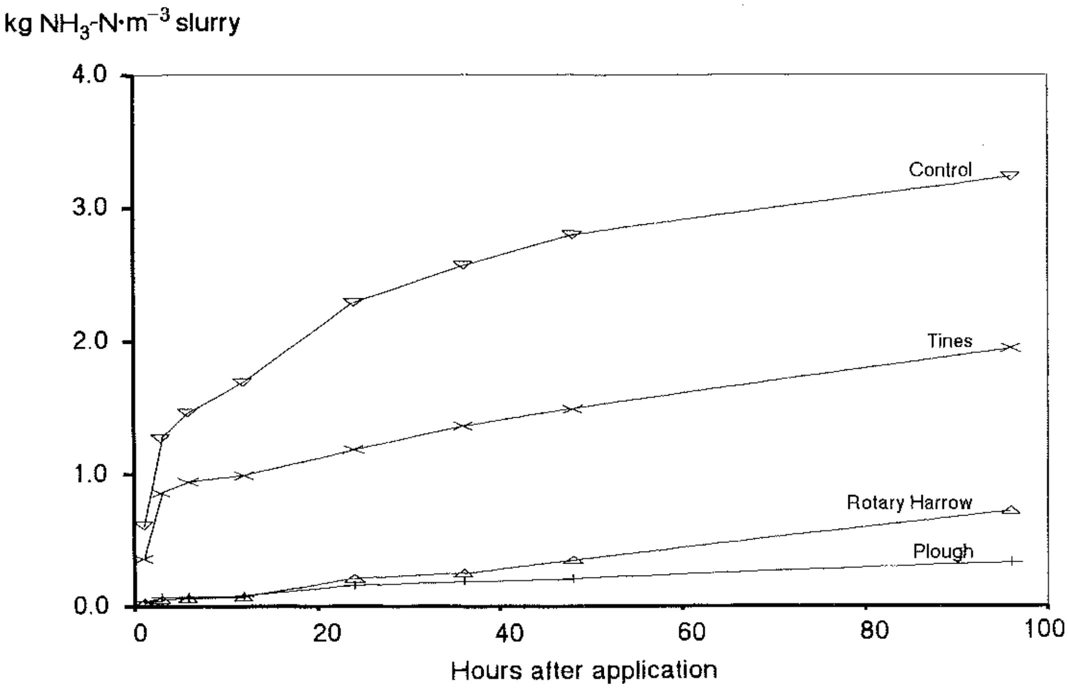

Figure 1. Cumulative emissions of ammonia during experiment M1.

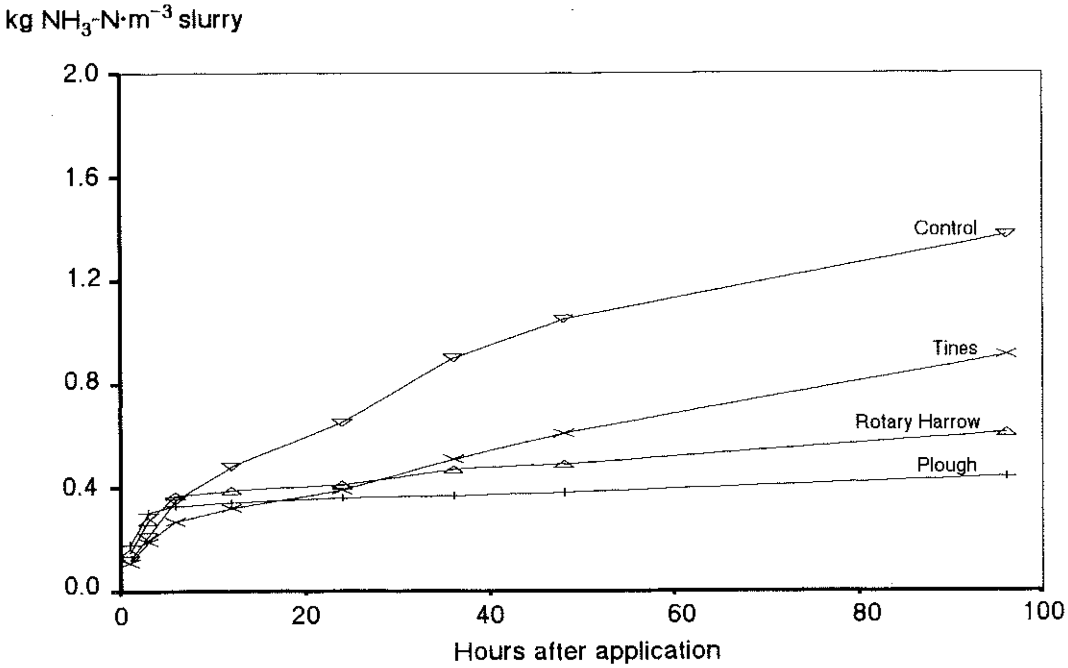

Figure 2. Cumulative emissions of ammonia during experiment M3.

The cumulative ammonia loss over 96 hours for experiments M1, M3 and M4 is illustrated in figures 1, 2 and 3 respectively. Following immediate incorporation of slurry (fig 1), ammonia

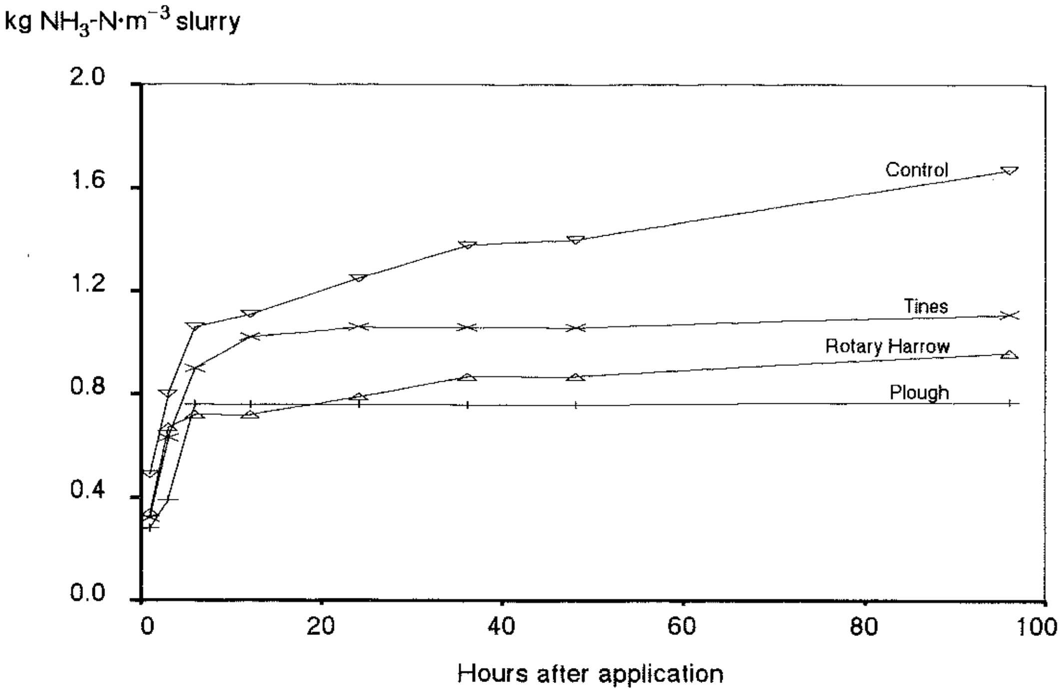

Figure 3. Cumulative emissions of ammonia during experiment M4.

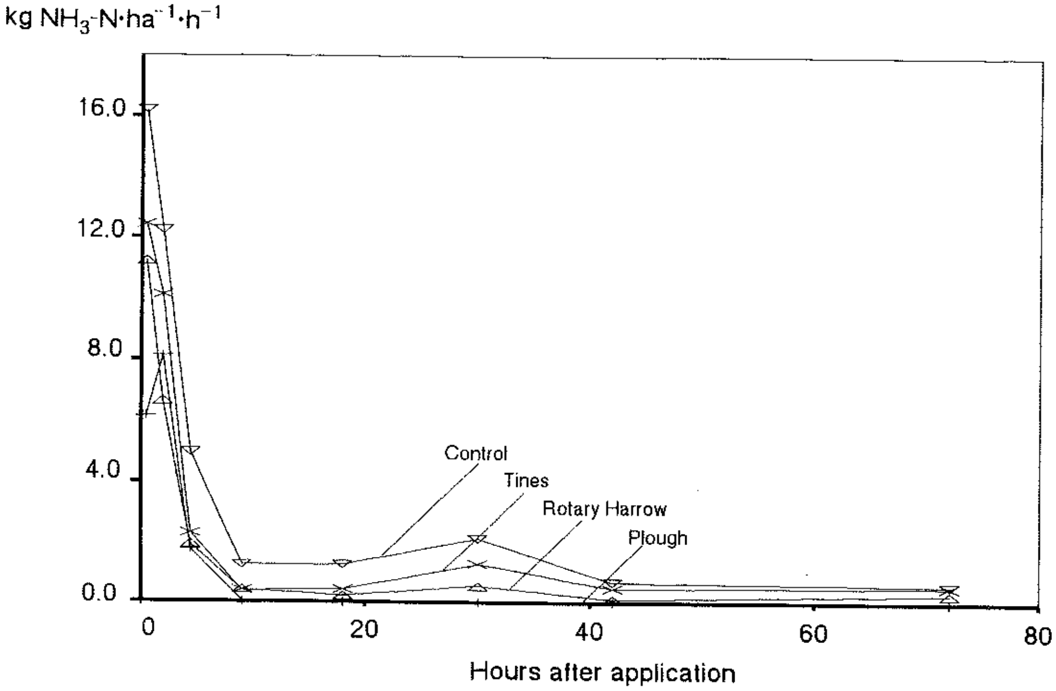

Figure 4. Rates of emission of ammonia during experiment M3.

emission continued from the ploughed, harrowed and tined plots, as well as from the control, for the duration of the experiment.

The rate of emission was markedly higher from the tined plot than from the ploughed or harrowed plot. Incorporating three hours after spreading (fig 2) prevented further ammonia loss from the ploughed plot but only temporarily reduced that from the other two incorporation treatments. The hourly rates of emission are illustrated in figure 4, together with the small diurnal fluctuations from the controls, rotary harrowed and tined plots 30 hours after spreading. The latter were due to changes in wind speed and temperature. Ploughing six hours after slurry application (fig 3) prevented further ammonia loss. As for the three hour delay, using a rotary harrow after six hours substantially reduced further loss of ammonia compared with the unincorporated control but loss continued at a relative high rate for several hours following incorporation with the rigid tines.

3.1.3 Ammonia emission during spreading

Ammonia emission during the spreading of 10 m^3 of slurry with a vacuum tanker was measured for experiments M1, M3 and M4. The results are summarized in table 5. Despite varying weather conditions during spreading for the three experiments, the total emissions were similar from each. These values were lower than those recorded in The Netherlands in 1987 (Pain and Klarenbeek, 1988), but about twice those recorded for spreading pig slurry with a similar type of machine in the UK (Phillips et al., 1990). Even so, the ammonia lost during spreading represented only between 0.1 and 0.3% of the total loss over 96 hours.

Table 5 Ammonia emissions during spreading of pig slurry with a conventional vacuum tanker

Expt	Rate of emission [mg $NH_3 \cdot s^{-1}$]	Total emission [g $NH_3 \cdot m^{-3}$ slurry]
M1	250	3.6
M3	215	4.7
M4	165	3.5

3.1.4 Odour emission following spreading

The data presented in figure 5 confirm the earlier findings that, as for ammonia, the pattern of odour emission is represented by an exponential decay curve. Rates of emission were high initially but rapidly decreased to much lower levels with small diurnal fluctuations. The initial rates of emission were $8.6 \cdot 10^3$, $31.4 \cdot 10^3$, $54.9 \cdot 10^3$ and $57.3 \cdot 10^3$ odour units$\cdot s^{-1} \cdot m^{-3}$ slurry applied for the plough, rotary harrow, rigid tines and unincorporated control plot respectively. This marked difference between the treatments was sustained for about five hours, after which there was no apparent influence of method of incorporation. Although the pattern of odour emission for the other experiments was similar to that in figure 5, reduction in odour emission was not detected when incorporation by any method was delayed for three or six hours after slurry application. The total odour emission over 48 hours for each method and time of incorporation is given in table 6. These data suggest that only ploughing immediately after spreading results in a worthwhile reduction in odour emission. Compared with the control, this treatment reduced emission by 52%, the rotary harrow by 20%.

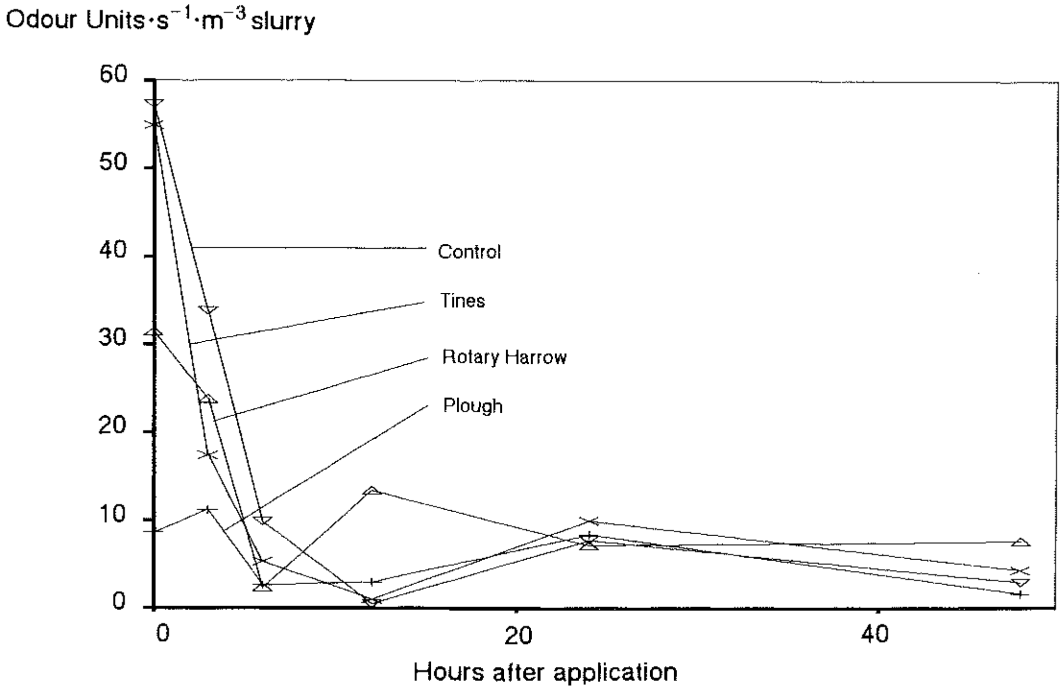

Figure 5. Rates of emission of odour during experiment M1.

Table 6 The influence of method and time of slurry incorporation on odour emissions over 48 hours

Incorporation	Odour emission [odour units $\cdot$ m^{-3} slurry]			
	incorporation method			control
	plough	rotary harrow	rigid tines	
Immediate	$681 \cdot 10^6$	$1133 \cdot 10^6$	$1586 \cdot 10^6$	$1409 \cdot 10^6$
3 hour delay	$994 \cdot 10^6$	$1178 \cdot 10^6$	$1026 \cdot 10^6$	$1072 \cdot 10^6$
6 hour delay	$583 \cdot 10^6$	$513 \cdot 10^6$	$578 \cdot 10^6$	$626 \cdot 10^6$

3.1.5 Odour emission during spreading

Odour emission during spreading was measured for experiments M1, M3 and M4. The results are presented in table 7. The total emission compared reasonably well with the value of $17.5 \cdot 10^6$ odour units $\cdot$ m^{-3} slurry applied in a single experiment in 1987 in The Netherlands (Pain and Klarenbeek, 1988), but was much greater than the mean value of $349 \cdot 10^3$ odour units $\cdot$ m^{-3} slurry applied, measured for pig slurry in the UK (Phillips et al., 1990). Similarly, the rate of odour emission was about 40% greater than that measured in The Netherlands in 1987, and over 70 times greater than that for UK pig slurry. Although odour measurements are likely to be associated with a high degree of variability, the differences between the results obtained in The Netherlands may be due in part to differences in the type of slurry spreaders and in the method of calculating the results. A small farm tanker was used for spreading slurry in 1987 and a large contractor's tanker with a higher discharge rate in 1988. In the 1987 Dutch experiment, the mean odour concentrations from 5 sampling points within the odour plume was used to calculate emission. In all the experiments conducted in 1988, the vertical variation in odour concentration within the plume was taken into account in calculating the results. The same methods were used for ammonia and the results indicate that emission of both odour and ammonia is greater from Dutch than from British pig slurries. Also, the results confirm the earlier findings that odour emission during spreading represents only a small proportion of that after spreading when slurry is lying on the soil surface.

Table 7 Odour emissions during spreading of pig slurry with a conventional vacuum tanker

Expt	Rate of emission [odour units $\cdot s^{-1}$]	Total emission [odour units $\cdot m^{-3}$ slurry]
M1	$604.5 \cdot 10^3$	$8.7 \cdot 10^6$
M3	$604.9 \cdot 10^3$	$13.2 \cdot 10^6$
M4	$954.0 \cdot 10^3$	$20.6 \cdot 10^6$
mean	$721.1 \cdot 10^3$	$14.2 \cdot 10^6$

3.2 Method and time of slurry incorporation: wind tunnel experiments

3.2.1 Ammonia emission

The results of wind tunnel experiments conducted on the polder adjacent to the micrometeorological experiments and at IMAG-DLO are presented in tables 8 and 9. On the

Table 8 Experiments T1-T3. Total ammonia loss over 96 hours following application of pig slurry

Expt	Incorporation		Ammonia loss	
	method	time [h]	total [kg NH_3-N $\cdot m^{-3}$ slurry]	% reduction compared with control
T1	Plough	0	0.10	97
	Rotary harrow	0	0.50	69
	Tines	0	0.39	76
	Control	0	1.64	–
T2	Plough	3	0.20	76
	Rotary harrow	3	0.64	23
	Tines	3	0.71	16
	Control	3	0.83	–
T3	Plough	6	0.45	71
	Rotary harrow	6	0.62	59
	Tines	6	0.71	54
	Control	6	1.51	–

polder, losses from the unincorporated control plots (table 8) were lower than those recorded from the micrometeorological experiments. This is probably due mainly to differences in the wind speed through the tunnels and the ambient wind speed and to the absence of rainfall on the areas beneath the tunnel canopies.

As for the micrometeorological experiments, ploughing was consistently the most effective method for reducing ammonia loss, resulting in a reduction of over 90% when carried out immediately after spreading. Although both were always less effective than ploughing, there was no clear distinction between the rotary harrow and rigid tines. Similarly, both these treatments resulted in an apparently greater reduction in ammonia loss when delayed by six hours (expt T3) than by three hours (expt T2).

Table 9 Experiments T4-T8. Total ammonia loss over 96 hours following application of pig slurry

Expt	Incorporation		Ammonia loss	
	method	time [h]	total [kg NH_3-N$\cdot$m^{-3} slurry]	% reduction compared with control
Mean of T4 & T5	Plough	0	0.04	92
	Rotavator	0	0.12	91
	Tines	0	0.41	69
	Control	0	1.31	–
Mean of T6 & T7	Plough	3	0.28	82
	Rotavator	3	0.37	77
	Tines	3	0.59	63
	Control	3	1.59	–
T8	Plough	6	0.33	61
	Rotavator	6	0.23	72
	Tines	6	0.39	55
	Control	6	0.84	–

For the experiments at IMAG-DLO, the mean results from experiments T4 and T5 (immediate incorporation) and those from experiments T6 and T7 (three hour delay) are summarized in table 9 together with results from a single experiment (expt T8) in which incorporation was delayed by six hours. Ammonia losses from the control plots were of the same order as those recorded on the polder. However, on this lighter soil, results from the ploughed and rotavated treatments were similar, with both resulting in a greater reduction in ammonia loss than the comparable treatments on the polder. The spring tines were always the least effective method of incorporation. For all three methods, the reduction in ammonia loss decreased with increasing time between spreading and incorporation.

Examples of the pattern of ammonia loss with time for immediate incorporation, a three hour delay and a six hour delay (expt T4, T6 and T8 respectively) are illustrated in figures 6, 7 and 8. Immediate incorporation by any of the three methods effectively controlled the initially high

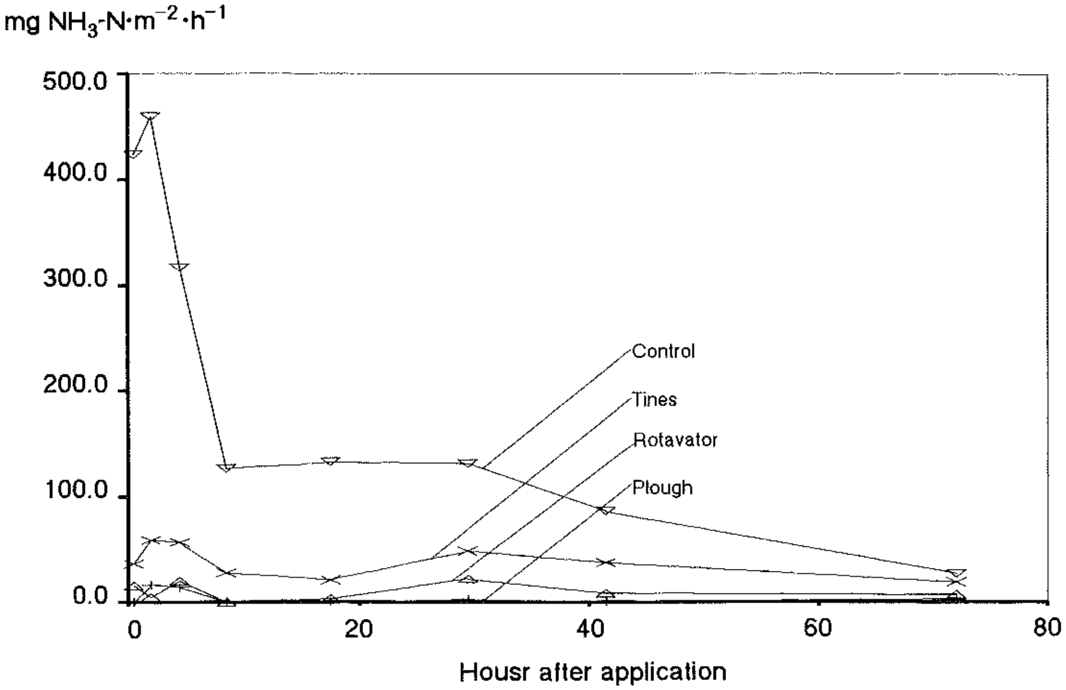

Figure 6. Rates of emission of ammonia during experiment T4.

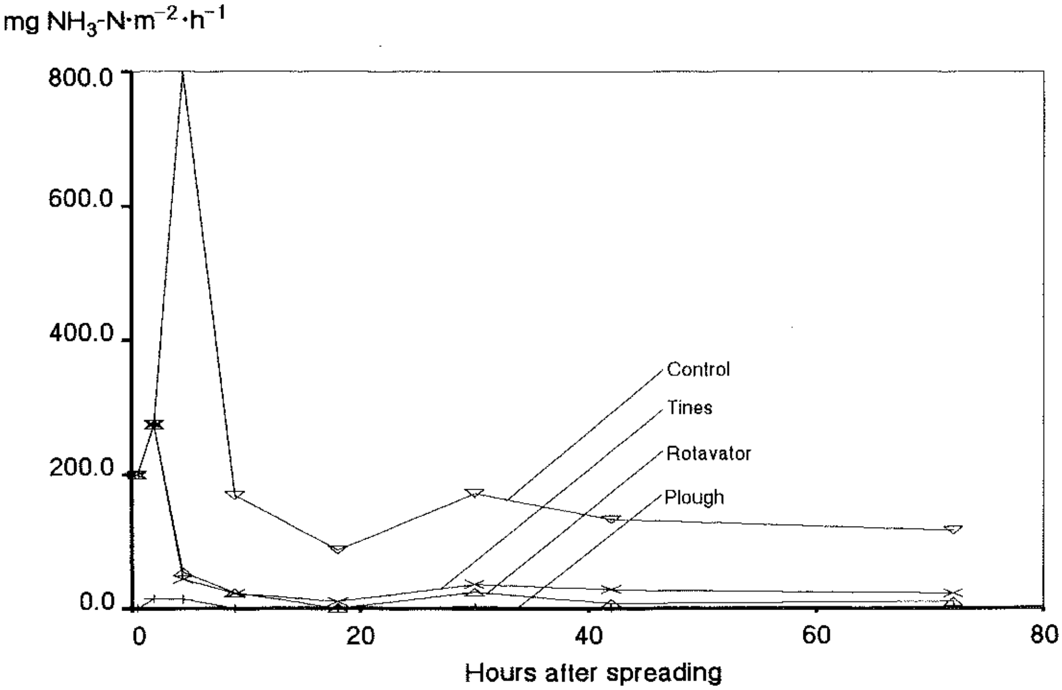

Figure 7. Rates of emission of ammonia during experiment T6.

rates of loss that are typical following the application of slurry to land. During the first hour after slurry application, the rate of loss from the control was over 400 mg NH_3-N·m^{-2}·h^{-1}, compared with 15 and 36 for the rotary harrow and tines respectively. Although consistently

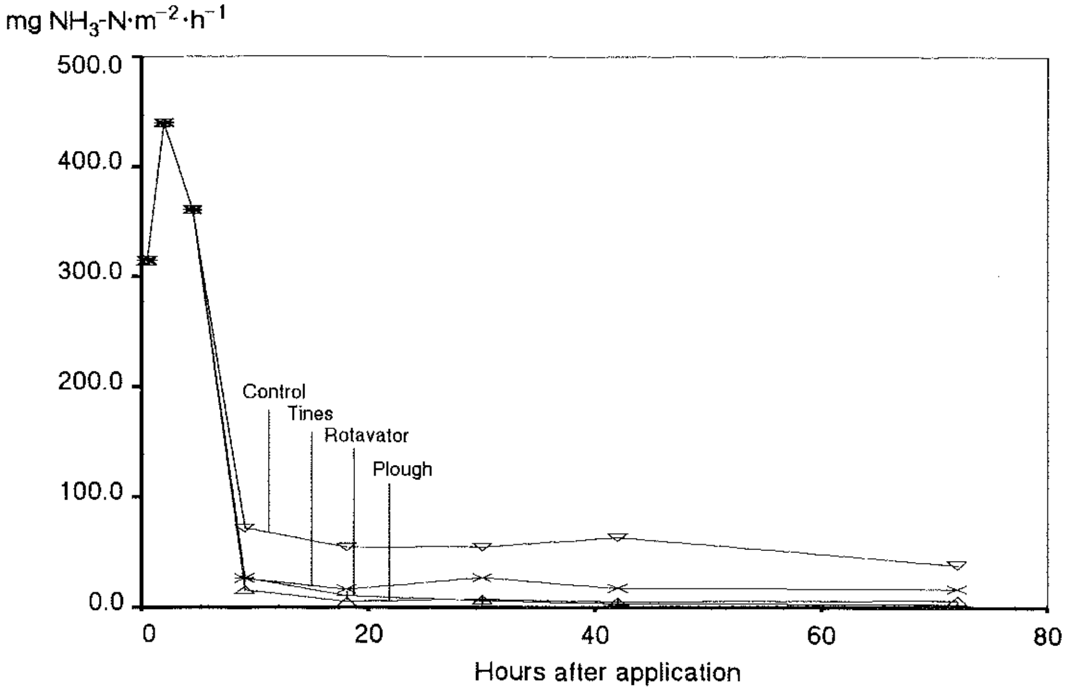

Figure 8. Rates of emission of ammonia during experiment T8.

lower than from the control, ammonia loss from the tined treatment remained higher than those from the other two incorporated treatments throughout the experiment.

Three hours after application, the rate of loss from the control continued to increase up to 800 mg NH_3-N$\cdot m^{-2}\cdot h^{-1}$ (figure 7). All three methods of incorporation resulted in much lower rates of loss which were sustained for the duration of the experiment. Since in this experiment, only 5% of the total loss from the control had occurred within three hours of application, delaying incorporation by three hours was almost as effective in reducing the total ammonia loss as incorporating immediately. Normally, a much higher proportion of the total loss occurs within a few hours of application, since rates of loss rapidly decrease as slurry infiltrates into the soil. Ponding of the slurry on the soil surface and rising temperatures in this experiment may have accounted for the observed pattern of ammonia loss.

By six hours after application, the rate of loss from the control was rapidly decreasing (figure 8). Incorporation increased the rate of decrease so that subsequent rates of loss from all incorporated treatments were uniformly low. Approximately 30% of the total loss from the control had occurred within six hours of application. Hence, delaying incorporation for this period was less effective than a three hour delay in reducing total losses.

The total losses of ammonia were underestimated in all these experiments since the experiment lasted for 96 hours only and losses are known to continue for about 15 days. However, normally, losses equivalent to 80 to 90% of the total are likely to occur within 96 hours of application.

3.3 Method of managing wastes in the piggery

3.3.1 Slurry analyses

Analyses and rates of application of the four different piggery wastes used in this experiment (expt M5) are given in table 10. As to be expected, there were major differences between the composition of the liquid and solid fractions from the in-house separator, the former comprising mainly liquid and the latter solids. In particular, 87% of the total N in the liquid was present as NH_4^+-N compared with 28% for the solid fractions. Despite the differences in management and storage, the composition of the slurries 1 and 2 were very similar except that the total solids content was lower for 1.

Table 10 Experiment M5. Analyses of wastes and rates of application

		Waste			
		liquid1)	solids2)	slurry 13)	slurry 24)
NH_4^+-N	$[mg \cdot l^{-1}]$	3890	2.9*	4390	4630
Total N	$[mg \cdot l^{-1}]$	4470	10.3*	6030	6600
Total P	$[g \cdot l^{-1}]$	16.3	3.7*	935	1870
Total K	$[mg \cdot l^{-1}]$	7040	6.1*	6230	6130
Total solids	[%]	2.4	16.6	5.7	9.2
pH		8.6	8.1	7.6	7.3
Volume applied	$[m^3 \cdot ha^{-1}]$	61.5	34.0	60.2	59.2
Rate of application:	$[kg\ NH_4^+\text{-}N \cdot ha^{-1}]$	239.2	98.5	264.5	274.2
	$[kg\ N \cdot ha^{-1}]$	274.9	349.7	363.3	390.9

* = $g \cdot kg^{-1}$
1) = liquid, primarily urine, from in-house belt separator
2) = solids, primarily faeces, from in-house belt separator
3) = slurry stored in a pit beneath the slatted floor for the entire fattening period
4) = slurry removed weekly and stored in enclosed tank

3.3.2 Ammonia emission

Following application to land, ammonia losses from slurries 1 and 2 were very similar (table 11) and within the range recorded for unincorporated control treatments in experiments M1-M4. The total and NH_4^+-N contents of liquid and solids were lower than those for the slurries used in the earlier experiments but the mean wind speeds were higher. During experiment M5, mean wind speed was 4.3 $m \cdot s^{-1}$ (max 7.19 $m \cdot s^{-1}$, min 2.23 $m \cdot s^{-1}$), mean air temperature 12.1 °C (max 14.0 °C, min 10.3 °C) and total rainfall 22.6 mm.

Ammonia loss from the liquid was less than 20% of that from the slurries even though the applications contained similar amounts of NH_4^+-N. Only 7-8% of the NH_4^+-N applied was lost through ammonia volatilization compared with over 30% from the slurries. Very rapid infiltration into the soil by this very dilute waste may explain the differences. Losses from the faeces were also lower than those from the two slurries, both on an area and on a volume basis. However, expressed as % of NH_4^+-N, the ammonia loss was in the same order as those of

Table 11 Experiment M5. Total ammonia loss over 72 hours following application of wastes to arable land

Waste	Ammonia loss			
	total		% NH_4^+-N applied	% total N applied
	kg NH_3-N·ha^{-1}	kg NH_3-N·m^{-3} waste applied		
Liquid	18.7	0.30	7.8	6.8
Solids	33.0	0.97	33.5	9.4
Slurry 1	97.2	1.61	36.8	24.9
Slurry 2	89.5	1.51	32.6	22.9

both slurries. This can be explained by the lower application rate of the faeces as compared to the slurry or liquid.

The contrast between the separated wastes and the slurries is illustrated in figure 9 which gives the cumulative ammonia losses during the 72 hours of the experiment. In common with the results from the previous experiments, high initial losses were followed by lower rates of loss which were continuing when measurements ceased 72 hours after application. Initial rates of loss were lower from the separated slurries, especially from the liquid fraction, and remained consistently lower than those from the slurries throughout the experiments. Losses from the liquid were not detected after 30 hours and from the solids after 45 hours.

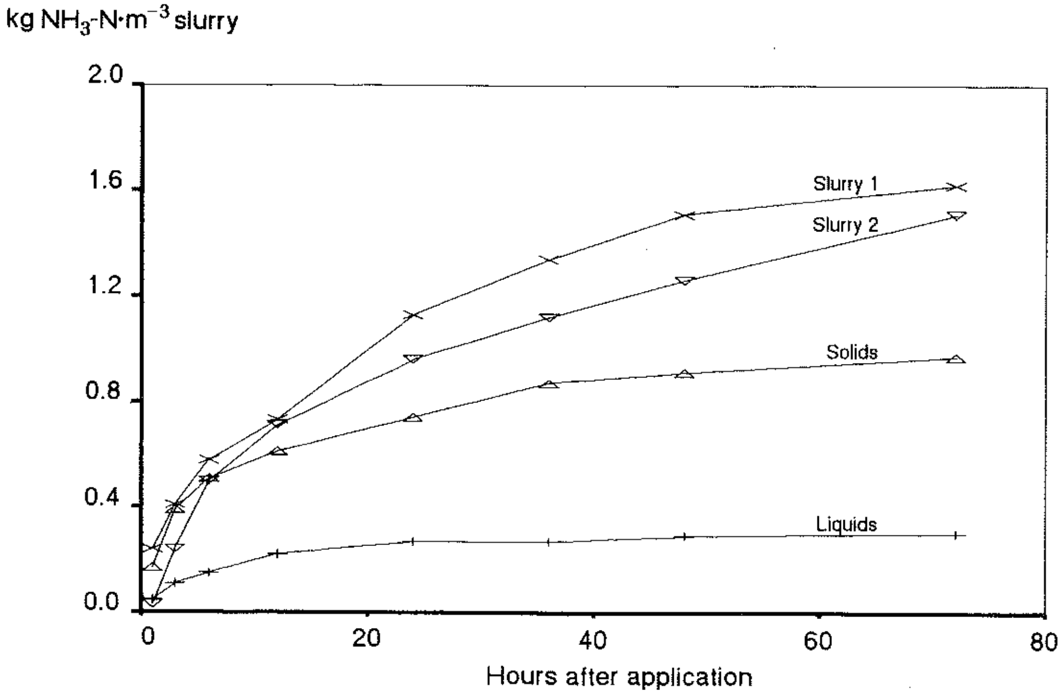

Figure 9. Cumulative emissions of ammonia during experiment M5.

Samenvatting

Emissies die ontstaan bij het uitrijden van mest zijn een bekend verschijnsel. De bestrijding ervan is verschillend geregeld in de diverse landen van Noordwest Europa. Zo wordt in het Verenigd Koninkrijk veel aandacht besteed aan het terugdringen van de geurproblematiek terwijl in Nederland de nadruk ligt op het verminderen van de ammoniakemissies.

Het tegengaan van emissies na het uitrijden van mest op bouwland is mogelijk door het toepassen van grondbewerkingstechnieken. Als gevolg hiervan wordt het mestoppervlak dat bloot staat aan de lucht verkleind. Tevens bevordert een grondbewerking het contact tussen de bodemdeeltjes en de mest waardoor de emissie verder afneemt.
Voor het inwerken van de mest na het uitrijden op bouwland zijn verschillende mogelijkheden voorhanden. Te denken valt aan onderploegen en het gebruik van een rotorkopeg of cultivator. Deze apparatuur is op het doorsnee akkerbouwbedrijf aanwezig.

Teneinde de genoemde technieken op effectiviteit te kunnen beoordelen, is een onderzoek uitgevoerd waarbij de mest werd ingewerkt op verschillende tijdstippen na het uitrijden. Hierbij is gekozen voor het moment direct na het uitrijden, 3 uur na het uitrijden en 6 uur na het uitrijden. Het onderzoek werd uitgevoerd op jonge zeeklei in zuidelijk Flevoland. De optredende emissies zijn gemeten met behulp van een micrometeorologische methode en met een windtunnelmethode.
Parallel aan het onderzoek op de kleigrond zijn de emissies gemeten op zandgrond met behulp van windtunnels.

Een andere methode om tot vermindering van de emissies na het uitrijden te komen, is het uitrijden van mest met een verlaagde hoeveelheid vluchtige componenten. Dit soort mest wordt doorgaans verkregen door één of andere vorm van mestbehandeling en/of opslag. Gedurende een periode van vier dagen zijn de emissies onderzocht van twee soorten mengmest die op verschillende wijze waren opgeslagen. Verder zijn de emissies onderzocht van de dikke en dunne mest afkomstig van een scheidingssysteem dat was ingebouwd onder de roosters van een mestvarkensstal.

In vergelijking met het controle-object geeft elk uitstel van inwerken een verhoging van de ammoniakemissie. Hoe langer gewacht wordt met het inwerken des te hoger wordt de totale emissie. Dit is van toepassing op klei- en zandgrond. Verder werd in alle proeven op kleigrond vastgesteld dat het onderploegen van mest een groter effect heeft op de emissievermindering dan het inwerken met een rotorkopeg. Ook op zandgrond geldt dat onderploegen een beter effect heeft dan een rotavator. Het gebruik van een cultivator is zowel op klei- als op zandgrond de minst effectieve methode voor vermindering van de ammoniakemissies.
Bij het uitrijden is vastgesteld dat de emissie uit mest, die frequent uit de stal werd verwijderd, nauwelijks verschilt van die van traditioneel opgeslagen mest. Het uitrijden van direct gescheiden mest kan een bijdrage leveren aan de gewenste emissievermindering. De ammoniakvervluchtiging bij urine was 5 x lager dan van het controle-object; de procentuele vervluchtiging ligt bij het uitrijden van faeces op hetzelfde niveau als die van de onbehandelde mest.

Het uitstellen van de grondbewerking leidt slechts in beperkte mate tot een verhoging van het geuremisssieniveau. Wel zijn verschillen te constateren tussen de diverse methoden van onderwerken.

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