MINISTRY OF AGRICULTURE, FISHERIES AND FOOD

Research and Development

Final Project Report

(Not to be used for LINK projects)

Date project completed:

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Section 1 : Identification sheet

1. (a)	MAFF Project Code	**OF0161**		
(b)	Project Title	THE ENVIRONMENTAL IMPLICATIONS OF MANURE USE IN ORGANIC FARMING SYSTEMS		
(c)	MAFF Project Officer			
(d)	Name and address of contractor	Postcode		
(e)	Contractor's Project Officer			
(f)	Project start date	01/08/1998	Project end date	30/11/1999
(g)	Final year costs:		**approved** expenditure	
			actual expenditure	
(h)	Total project costs / total staff input:		**approved** project expenditure	
			actual project expenditure	
			***approved** staff input	
			***actual** staff input	
(i)	Date report sent to MAFF			
(j)	Is there any Intellectual Property arising from this project ?			

***staff years of direct science effort**

Section 2 : Scientific objectives / Milestones

2. Please list the scientific objectives as set out in CSG 7 (ROAME B). If necessary these can be expressed in an abbreviated form. Indicate where amendments have been agreed with the MAFF Project Officer, giving the date of amendment.

The overall objective was to review the environmental impact of manure use in organic farming systems. More specifically, the objectives of the project were:

1. To review the use of manures in organic farming systems.
2. To compare the nutrient (and heavy metal) composition of cattle manures derived from organic and conventionally farmed animals.
3. To review the environmental impacts of manure use in organic farming systems, focusing primarily on the flows of nitrogen (nitrate, ammonia and nitrous oxide) and methane.
4. To provide recommendations on the best practice for use of organic manures in organic systems.

3. List the primary milestones for the final year.

It is the responsibility of the contractor to check fully that ALL primary milestones have been met and to provide a detailed explanation if this has not proved possible

Milestones		Target date	Milestones met?	
Number	Title		in full	on time

If any milestones have not been met in the final year, an explanation should be included in Section 5.

Section 3 : Declaration

4. I declare that the information I have given in this report is correct to the best of my knowledge and belief. I understand that the information contained in this form may be held on a computer system.

Signature Date

Name

Position in Organisation

Section 4 : Executive summary

A desk study was undertaken (a) to identify the important N flows in three types of organic farming systems (extensive upland, intensive lowland mixed and stockless vegetable systems) in relation to manure use and (b) to determine the effects of changed management practice on these flows. A study of the published literature has highlighted the key stages for nutrient management prior to land spreading.

Dietary inputs - amounts of N excreted and the partitioning between urine and faeces is important in determining the fate of N through the farming system. Diet affects this partition, but we were unable to find evidence of differences between organic and non-organic rations. Clearly, a crude N balance (N in feed - N in milk) provides a good guide to risk. Because N removal in milk is a small component, the more intensive systems are likely to generate more N as excreta.

Housing - it is estimated that, in the UK, NH_3 losses from housing constitute *c.* 35% of the total NH_3 emissions from cattle production systems (compared with 14% from manure storage) and about 20% of total N_2O emissions. The limited available information suggests that losses by NH_3 emission during housing are larger from slurry based systems than from cattle housed on straw. The converse is true of N_2O losses.

Solid manure storage - composting offers advantages (namely sterilisation) but also can exacerbate loss of nitrogen as NH_3, due to the heat generated and regular aeration by turning of the heap during the early stages. Losses of up to almost 80% of the total N have been reported. There is a strong link with C:N ratio (and, therefore, straw amount), and our analysis of the numerous experiments suggests that the C:N ratio should be >30 at the start of composting to retain N (i.e. to reduce losses to <10%). Loose covering had little effect on retaining nitrogen. NPK are lost in leachate during manure storage (but only represent a true loss if the leachate is not collected for recycling).

Slurry storage - losses are predominantly as NH_3 and, we calculate, are typically 0.05% (winter) - 0.1% (summer) of the total N content per day. A crust would approximately halve losses. Stirring breaks any crust and also brings more ammonium to the slurry surface, thereby increasing volatilisation. Aeration would have similar effects, but may also increase N_2O emissions if it produces intermittent aerobic and anaerobic conditions. Covering stores would substantially decrease losses and options range from straw to concrete structures. Effectiveness increases with cost!

A simple N model was constructed to calculate the integrated effects of management practices during housing and storage. Our calculations suggested that an all-slurry system (though not permitted under organic regulations) would retain more N than a straw-based system: losses from slurry are greater during housing, but less during storage (assuming the slurry lagoon is covered or has a crust and is not regularly stirred - regular agitation removes this differential between slurry and FYM). However, increasing the proportion of slurry in a system shifts the risk of N loss to the field (as ammonia and nitrate in particular): N losses from FYM during this stage are less, especially if composting has decreased the ammonium N content of the manure.

The question that inevitably will be asked is ‘do conventionally managed systems provide more of a risk than organic systems?’ There is no straightforward answer. Many of the loss processes from manure will be the same between systems but they will be modified by management and by the intensity of the enterprise. It is this latter point - i.e. the nutrient balance - that will have most impact on any comparison; farms with a large nutrient excess will be more prone to large losses. Thus, generally, organic farms provide less emissions than conventional farming systems involving livestock. The move to more solid based systems should result in smaller losses of N during housing, but practical measures to reduce losses during storage need to be investigated.

The review has highlighted areas where further information is required. We can also use existing information about management of conventionally produced manures to provide guidance on minimising losses, thereby retaining more of an important nutrient in the farming system. This is reflected in the organic standards which show good agreement with Air, Water and Soil Codes published by MAFF.

The outcome of all management processes is the production of manures that vary widely in composition between farms and, often, within farms. Our analysis of 14 cattle slurries and 45 cattle manures confirm the wide variations in nutrient contents as affected by many management factors. Generally, NPK values were *c.* 20-40% less than published values for ‘conventionally’ produced manures (although these mean values were also associated with a wide range of values). This probably reflects the lower intensity of organic production systems.

Section 5 : Scientific report

Introduction

Environmental impacts

The UK Ministry of Agriculture's policy objectives are to minimise the total environmental impact of nitrogen losses from agriculture, and to comply with international legislation. In particular, the EC Nitrate Directive (91/76, Anon. 1991) requires the UK Government to implement measures that will reduce nitrate losses from soils. Also, the UNECE is considering revision of the convention on Long-Range Transboundary Air Pollution to include recommendations to reduce ammonia emissions. Under the UN Framework Climate Change Convention, the UK is committed to returning emissions of greenhouse gases to 1990 levels by 2000. Nitrate, ammonia and other forms of pollution from livestock farming are linked under the EC Directive on Integrated Pollution Prevention and Control (IPPC) and there will be a need to develop integrated strategies to ensure that conserving one form of nitrogen does not lead to unacceptable losses in another form.

Rules for minimising nitrate leaching are well recognised (Prins *et al*., 1988). Systems studies (Shepherd & Lord, 1996; Johnson *et al*., 1997) suggest that changes to farm practice can decrease nitrate leaching, and this has been confirmed by monitoring in the Nitrate Sensitive Areas (Lord, 1994). Recent research has concluded that nitrate losses from organic systems are generally smaller than from conventional systems, although losses following the ploughing of grass leys can represent a serious pollution risk (EFRC, 1997; Anon., 1998).

However, the real management challenge involves better utilisation of animal manures, as they can contribute substantially to nitrate loss (Smith & Chambers, 1998). Land spreading of manure is also a major ammonia source (Pain *et al*., 1998). Nitrous oxide measurements are less certain, but it has been shown in Sweden that losses from manure can be as great as from fertiliser (Robertson, 1991). In the UK, it is estimated that housing and storage are greater contributors but losses from land spreading are still large with estimates of about 9 kt N_2O-N/year.

Rules to minimise ammonia and nitrate losses from manures are straightforward: avoid autumn applications to decrease nitrate loss (Smith & Chambers, 1993), incorporate manures quickly to minimise volatilisation (Pain *et al*., 1991). No guidance as yet is given for nitrous oxide, although it has been suggested (Granli & Bockman, 1994) that practices advocated in current UK Codes of Good Agricultural Practice will help to minimise nitrous oxide emissions from soils.

Most nitrous oxide is emitted from warm, wet soils (Matson *et al.*, 1992). Emissions increase when there is an excess of nitrifiable N. A labile pool of organic carbon can generally also increase losses. Manure applications (especially those with large proportions of uric or ammonium-N, such as poultry manure or pig slurry) can provide both N and C. Management practices can cause conflicts between pathways. For example, rapid incorporation to decrease ammonia loss could induce conditions which increase nitrous oxide emissions (Comfort *et al*., 1990). Decreasing volatilisation also increases the N pool available for leaching. Winter or spring, rather than autumn, applications of manure are favoured to minimise nitrate leaching. However, larger nitrous oxide emissions have been measured (Allen *et al.*, 1996) from applications of animal excreta in autumn/winter than in spring/summer (presumably because of less crop activity to decrease the labile N pool).

Conventional livestock production systems are therefore seen as important sources of nitrate, ammonia, nitrous oxide and methane. These production systems can be especially intensive, with large nitrogen surpluses produced on the farms. With an increasing desire by the public and policy makers for more sustainable farming methods, there is renewed interest in organic farming. Many organic systems are mixed systems with a reliance on manure for soil fertility building. Therefore, information is as equally needed on the impacts of these systems on N and methane losses to the wider environment from manure. However, there is also a need to identify and quantify the main N loss pathways so as to adopt practices that retain this valuable nutrient within the soil-crop system.

Manure nutrient content

There have been many data collected on the nutrient composition and environmental impact of manures in conventional farming systems, which have provided the basis for published average NPK values (e.g. in MAFF fertiliser recommendations, Anon., 1994). This has provided farmers with robust information for the formulation of their additional fertiliser needs. However, organic farming systems differ in three main respects:

- the employment of crop rotations which contain legumes for N fixation and the reliance upon recycling animal and crop residues for NPK
- animal diets rely on mainly forage with only a limited concentrate input
- manure management practices can be considerably different to those in conventional systems

Since most available data on manures has been, to date, based on conventional production, better information is required for organically produced manures to enable farmers a better capability for nutrient planning. This might be more important if ‘conventional’ manure cannot be used in organic systems; this is currently under debate. The increased interest in organic farming by the government, supermarkets and consumers, means that information specifically for organic systems is needed.

Recent research into the composition and utilisation of organic manures in conventional farming systems has led to improved advice (Anon., 1994). This is reflected in the development of MANNER a MANure Nitrogen Evaluation Routine, designed to provide a quick estimate of the fate of manure N following land applications for a range of agricultural situations, based on manure analysis (Chambers *et al*., 1999). Organic systems are not, however, specifically included. The composition of manures derived from organic and conventionally farmed animals has not been compared under UK conditions. If similar, then much of the research already undertaken in conventional systems would be directly transferable to the organic sector.

Objectives

The overall objective was to review the environmental impact of manure use in organic farming systems.

More specifically, the objectives of the project were:

1. To review the use of manures in organic farming systems.
2. To review the environmental impacts of manure use in organic farming systems, focusing primarily on the flows of nitrogen (nitrate, ammonia and nitrous oxide) and methane.
3. To provide recommendations on the best practice for use of organic manures in organic systems.
4. To compare the nutrient (and heavy metal) composition of cattle manures derived from organic and conventionally farmed animals.

Methods

1. Project group

The project was undertaken by four organisations: ADAS Gleadthorpe, EFRC, HDRA and IGER North Wyke.

2. Literature review

The project was primarily a desk study in which we addressed objectives 1-3 by:

- reviewing the current rules and regulations governing manure use in organic farming and compared them with guidelines/rules for conventional farming systems.
- reviewing the flows of N (and, to a lesser extent, methane) during animal housing and manure storage, and after landspreading. This included construction of a simple spreadsheet-based model to estimate N losses and the effects of management practices during housing.
- constructing balance sheets to identify the main N losses from manure in three typical organic systems: upland extensive; mixed lowland; stockless arable.
- drawing conclusions about the main N loss routes and possible ameliorative actions.
- suggesting directions for future research.

3. Manure analysis
The study focused on cattle manures because this is currently the largest organic sector in the UK. Thirty organic farms were visited during autumn 1998 and representative samples (c. 3 kg) of FYM or slurry were collected from the stores. A standard method for manure sampling was adopted thus: ten points were identified in the manure heap, the surface layer removed and two small sub-samples collected (making 20 sub-samples in total). After thorough mixing to provide a representative sample, *c*. 3 kg was taken for laboratory analysis. A similar approach of taking several small sub-samples to make a representative sample was also used for slurry collection. The manures were sealed into containers and kept cool for storage and transit to a central processing unit. Here, samples were again mixed to try to ensure a homogenous sample and a 1 kg sub-sample removed for despatch to the laboratory.

Farmers were asked to provide details of manure origin, age and management. Forty five FYM samples and fourteen slurry samples were collected.

The manure nutrient and metals contents were determined by standard analytical techniques (Anon., 1986). All nitrogen analyses were undertaken on fresh samples (to avoid loss of ammonia during drying); all other analyses were undertaken on dried samples.

Results and Discussion

1. Environmental implications of manure use
All of this information has been presented to MAFF in a separate, full report. Therefore, here we present only the main conclusions from our research since a complete account can be found in the review.

<u>(a) Regulations and Codes of Practice</u>

1. The Codes are reinforced by the Organic Standards: there is no contradiction.
2. By following the Codes of Good Agricultural Practice, manure storage, handling and use on all farms should not cause a serious risk of pollution. However, there is no programme of inspections of facilities on conventional farms and as the Codes are written as <u>voluntary</u> Codes there is no obligation for farmers to follow them. In comparison to conventional farms, <u>all organic farms are inspected at least once a year</u>. This includes an inspection of manure and slurry handling and a review of its use on the farm. If facilities/practices are found to be unacceptable an organic farmer is made to correct the deficiencies.
3. In addition, manures are seen as a valuable resource on an organic farm, not a waste product as sometimes the case on conventional farms. This in itself often results in better storage, handling and use on organic farms.
4. There will soon be regulations affecting some holdings (particularly large pig and poultry enterprises) in relation to gaseous emissions under IPPC, e.g. injecting of slurry, incorporation of manures after spreading. However, the current size of organic holdings means that IPPC in full would have little or no impact on the organic sector, in the short-term. However, it likely that UNECE or EU activities to reduce gaseous emissions are likely to lead to controls on most livestock farms over the coming years: this may affect some organic practices.
5. At present most organic farmers spread manure onto grassland, during a fertility building stage, where the nitrogen will be used by the growing crop. If incorporation after spreading was required by law, the application stage would move to fallow land, where leaching would be more likely. This example highlights the need for future regulations to be carefully assessed and discussed with organic bodies to ensure best practice is achieved.

<u>(b) Pre-spreading losses: impacts of diet</u>

1. Increasingly, organic livestock diets will be farm produced or organic protein sourced as the need to ring-

fence becomes more of an issue and the 20% conventional allowance is withdrawn.

2. The relationship between diet and N excretion is complex, depending on many interacting factors. Though there may be differences in both amount and quality of feed N intake between organic and conventional herds, we surmise that this is not necessarily so, nor is it likely to have a large effect on N excretion rates or partitioning during the housing phase. There may be differences during grazing, but further work (possibly direct measurement of excretal outputs) is required in all of these aspects.
3. This is particularly important because N amount and form will determine all of the N loss from manure thereafter.
4. Subsequent calculations in this review were based on best estimates to date.

(c) Pre-spreading losses: housing

1. There is large variability in emissions from housing because it is affected by many factors.
2. Diet, if it affects total N excretion and/or N partitioning will influence gaseous N emissions: there is no specific research that addresses this point.
3. In organic systems, with straw based housing the norm, ammonia losses will generally be reduced and there will be small increases in nitrous oxide and methane emissions, compared with slurry based systems.

(d) Pre-spreading losses: solid manure storage

1. Nitrogen losses are almost an inevitable consequence of manure storage, following the order NH_3=NO_3>>N_2O. There is, however, some scope for decreasing losses by management changes.
2. Generally, the more aerobic the manure storage system, the greater the potential for ammonia loss. Even so, reported values vary between 5-80% of the manure total N content.
3. Important factors are C:N ratio of the manure and NH_4-N content. However, C:N ratio should be >25-35 to minimise losses: this is often impractical with cattle manure, requiring large amounts of straw per cow.
4. Surprisingly, covering the heaps did not decrease N loss as NH_3, nor as leachate.
5. Anaerobic storage can greatly decrease NH_3 loss but a greater degree of management is required to ensure anaerobic conditions.
6. N_2O losses are small in terms of nutrient value (<5-6% of total N), but will still be environmentally important. Manure heaps have a large potential for denitrification, but the presence of nitrate is often the limiting pathway. Further, the likely end product is N_2 because conditions favour this.
7. The size of losses from stockpiled manures, as NH_3 or N_2O, would fall somewhere between the two management extremes of composting and anaerobic heaps because there will be both conditions within the stacked manure.
8. Nitrogen leaching from the manure heap is only a loss from the system if it is not collected. It then also provides an environmental threat. Losses of N were generally <5%, but leachate can be concentrated at the start of storage (concentrations will decline as N is immobilised or lost).
9. Covering had little effect on N loss, but decreased leachate volume.
10. As a whole, methane emissions during manure storage constitute about 5% of total emissions and are therefore not a major component of losses. On individual holdings the relative proportions will depend on manure handling: losses are much larger from stockpiled manure than from slurry. Furthermore, recent work suggests increased emissions with more straw addition, but further work is required here. Thus there might be a balance to be struck between reducing ammonia losses and increasing methane emissions from solid manures.
11. Composting, because it maintains aerobic conditions would reduce CH_4 emissions; losses would be greater

from stockpiled manures (but with greater risk of ammonia losses).

(e) Pre-spreading losses: liquid manure storage

1. Ammonia loss is the predominant pathway from slurry stores; nitrous oxide emissions are considered negligible, because there is generally little nitrate present in slurry (unless aerated - see later).
2. Covering the slurry or allowing it to crust is an effective method of decreasing losses. Regular agitation will increase ammonium movement to the slurry surface, thus exacerbating losses.
3. In theory, aeration of slurry offers the same advantages as composting solid manure: sterilisation, reduction of odours. The end point is conversion of organic N and ammonium-N to nitrate. However, as with composting, aeration can increase volatilisation losses. Also, if anaerobic conditions return, nitrate will be denitrified. Successful aeration is costly.

(f) Pre-spreading losses: overall effects

1. Considering the overall effects of management practices on the whole system is important because losses at any point in the system will be influenced also by changes before that point.
2. Increasing straw allowance per cow from 1 to 2 tonnes could halve housing losses of NH_3 and, also, decreases losses during manure storage. Thus, straw would impact throughout the system.
3. We estimate that composting half of the produced manure could double NH_3 losses during storage, compared with stockpiling the manure. This confirms the risks associated with composting manure with a narrow C:N ratio.
4. Generally, we estimate that management effects on nitrous oxide emissions would be small.

(g) Integrated losses: Upland farm

1. The conventional extensive upland farm is quite similar to an organic farm in its stocking rates and nutrient management and therefore nutrient budget.
2. We judge the environmental impact of such systems (in terms of N losses) to be quite small: calculated N surpluses of *c*. 23 kg/ha (or 17 kg/ha after accounting for losses).
3. Of the N loss pathways, N leaching from grazing was the largest. Ammonia losses from housing, and volatilisation losses during manure storage would be the major route for gaseous emissions.

(h) Integrated losses: Lowland farm

1. The calculated nutrient budget shows that the model farm is approximately in balance for P and K, with a N surplus of *c.* 6 t, or 100 kg/ha before accounting for losses.
2. Losses accounted for *c.* 3 t of the surplus N, and could be modified by changes in management practice, particularly during the housing and storage phases as discussed above.
3. Approximately 35% of the total N loss was via gaseous emissions of NH_3 (90%) and N_2O (10%). The remaining loss (65%) was via leaching, with the first year after a ley being the most ‘leaky’. This phase of the rotation has been previously noted as causing most risk. However, taking the manure component only, the largest loss pathway was as NH_3.
4. Approximately 3.7 t N or 66 kg/ha was therefore retained within the system (leading to possible increases in SOM). Comparisons within the literature suggest that surpluses from conventional dairy systems are double this. Moreover, the calculated ammonia emission per cow for our model farm (*c.* 18 kg NH_3) is generally less than published data for conventional farms.
5. Clearly it is important to minimise losses. However, losses have to be accounted for in the overall farm nutrient balance when the sustainability of a system is being judged: our calculation shows that the apparent

surplus was halved after accounting for N losses.

6. There are practical management tools to reduce N losses from manure in the system: manure timing and method of application, and modification to housing and manure storage practices.
7. Losses associated with grazing are less easy to manage. However, as ammonia losses from excreta increase with increasing N input, volatilisation from organic pasture will be less than from intensively fertilised pasture.
8. The limited amount of data suggest that most methane emission is associated with the animal rather than other management practices. Therefore, a switch to organic management is likely to have only a small impact on total methane emissions: the largest effect would be increased emissions associated with an increase in solid, as opposed to liquid, manure storage.

<u>(i) Integrated losses: Stockless system</u>

1. Examining the values for inputs and losses has highlighted major problems with construction of a complete and meaningful nutrient budget for a stockless horticultural rotation.
2. Within the context of a nutrient budget desk exercise apparent nitrogen surpluses are required to buffer the system as most of the nitrogen inputs on organic farms are in the form of organic matter and therefore only available over long periods.
3. Most work to date appears to have concentrated on two rotational phases - fertility building leys followed by exploitative arable crops. The transitional period is crucial both in terms of pollution prevention and to ensure adequate nutrient supply. In contrast to this approach the role of short term green manure crops - their potential within the cropping system and their impact on the environment - needs to be further explored.
4. *Contribution of N from the leys* - The contribution of nitrogen from grass/clover leys is crucial yet basic information concerning the quantities of nutrients fixed and their subsequent mineralisation remains uncertain. Cut and mulched regimes as used in stockless organic systems have been much less studied than grazed grassland and would be particularly worthy of further investigation.
5. *Gaseous losses* - In the budgets constructed above gaseous losses were considered to be negligible. However very little work has been done under circumstances relevant to the present study. It is possible that under certain conditions gaseous losses could be considerable e.g. when a green manure crop is mown and allowed to lie on the soil surface for some time before incorporation.
6. *Use of green waste compost* - For true stockless systems the use of green waste compost can provide a useful alternative to FYM which may be difficult to obtain in certain areas. The use of waste derived compost in agriculture clearly has wider environmental benefits in terms of reducing the amount of material landfilled; the environmental implications of using such material in a farm situation must, however, be fully evaluated before its use can be widely advocated. While land spreading of FYM can be a cause for concern, due to volatilisation of nitrogen and odour emissions, the spreading of compost eliminates these problems due to its inert nature.

2. Manure composition

1. Organic cattle manures, on average, have a lower NPK content than the published, average data for conventionally produced manures (Tables 1 & 2). This is perhaps not surprising and reflects the lower intensity of organic animal production and the generally smaller nutrient surpluses associated with these systems.
2. The data are in good agreement with published European data from organic systems.
3. However, there are many similarities with conventionally produced manures, so that much information about manure management practices derived from conventional systems is directly transferable to the organic sector.

4. Most N in FYM is in organic form and therefore represents a low risk of losses as NH_3 or NO_3. Slurry has a larger ammonium component, providing a larger risk after land application.
5. Manure metal contents are small (Tables 3 & 4), with loadings typically of g/ha from 'normal' application rates. Even with recycling within the farming system, soil metal accumulation would be slow, therefore.

Table 1. Slurry nutrient composition (n = 14) and comparison with published data. Composition expressed on a fresh weight basis. Composition expressed as a fresh weight basis. 'UK' refers to data for conventional cattle manures, based on recent measurements of 223 samples.

					Dewes & Hunsche		UK
		mean	range	sd	mean	sd	Conv.
pH		7.7	6.8-8.6	0.52	7.3	0.2	-
DM (%)		7.9	1.0-12.0	3.57	6.4	3.2	7.5
Total N	(kg/m³)	2.5	0.3-4.1	1.19	2.2	0.8	3.4
P_2O_5	(kg/m³)	0.96	0.20-1.50	0.433	0.9	0.5	1.5
K_2O	(kg/m³)	2.5	0.7-4.0	1.16	3.0	1.0	4.0
MgO	(kg/m³)	0.53	0.1-0.80	0.240	0.5	0.3	-
SO_3	(kg/m³)	0.72	0.1-1.30	0.326	-	-	-
NH_4-N	(kg/m³)	0.74	0.2-1.30	0.348	-	-	1.4
NO_3N	(kg/m³)	0.01	0.00-0.10	0.027	0.1	0.2	-
NH_4-N/TotN (%)		35	14-62	14.4	39	9.4	41

Table 2. Summary of mean nutrient contents from the collected manures (n = 43) and comparison with published data. Composition expressed as a fresh weight basis. 'UK' refers to data for conventional cattle manures, based on recent measurement of 62 samples.

				Dewes & Hunsche		UK
	mean	range	sd	mean	sd	Conv.
pH	8.5		0.28	8.4	0.6	-
DM (%)	21.0	13.0-38.0	5.83	21.8	5.8	26
Total N (kg/t)	5.2	2.9-7.8	1.16	4.9	1.4	6.3
P_2O_5 (kg/t)	2.4	1.1-4.2	0.84	2.8	1.3	4.1
K_2O (kg/t)	6.6	3.2-11.8	2.29	8.0	4.7	10.8
MgO (kg/t)	1.6	0.5-9.2	1.60	1.3	0.6	-
SO_3 (kg/t)	2.0	0.9-4.5	0.75	-	-	-
NH_4-N (kg/t)	0.26	0.03-1.11	0.267	-	-	0.77
NO_3N (kg/t)	0.06	0.00-0.72	0.149	-	-	-
NH_4-N/Total N (%)	5.5	0.4-25.8	5.99	8.4	8.1	12.2

Table 3. Summary of slurry metal contents

	SA[1] (mg/kg DM)	Dry matter basis (mg/kg) mean	range	sd	Fresh weight basis (g/m³) mean	range	sd
Pb	250	3.47	0.5 - 7.3	2.483	0.3	0.03 - 0.9	0.25
Ni	100	3.99	1.60 - 6.60	1.598	0.3	0.05 - 0.8	0.21
Zn	1000	102	57 - 170	34.4	8.3	1.4 - 19.9	4.78
Cd	10	0.21	0.12 - 0.29	0.071	0.02	0.0 - 0.03	0.009
Cr*	1000	(2.5)	-	-	(0.3)	-	-
Cu	400	50.5	15.0 - 19.9	54.7	3.3	0.2 - 11.5	2.96
Hg*	2	(0.03)	-	-	(0.003)	-	-

[1]Current Soil Association limits
*Most data at or below limit of detection

Table 4. Summary of FYM metal contents (n=43)

	SA[1]	Dry matter basis (mg/kg) mean	range	sd	Fresh wt basis (g/t) mean	range	sd
Pb	250	5.6	0.5 - 39.8	6.78	1.2	0.1 - 11.5	1.85
Ni	100	3.8	0.5 - 21.7	3.54	0.8	0.1 - 6.3	1.05
Zn	1000	111.6	21.8 - 551	97.6	24.3	5.5 - 159.8	29.68
Cd	10	0.3	0.1 - 1.15	0.212	0.07	0.02 - 0.33	0.065
*Cr	1000	2.8	2.5 - 6.7	1.00	0.6	0.3 - 1.9	0.313
Cu	400	27.8	4.8 - 120	19.9	5.9	1.1 - 34.8	5.66
Hg	2	0.04	0.0 - 0.07	0.019	0.01	0.00 - 0.02	0.004

[1]Current Soil Association limits
*levels generally below the limit of detection

Practical Implications

Losses of nitrogen - a valuable nutrient - (and methane) are inevitable from any farming system: the size of losses and relative importance of each loss pathway, however, will be affected by management decisions.

Our study also shows that it is necessary to consider the system as a whole. A good, although extreme, comparison would be between liquid and solid management systems for manure storage. Although not permissible under organic systems, the extreme would be a comparison between managing all manure as slurry or all manure as FYM. Our calculations suggest that pre-spreading losses would be greater from the solid system, particularly if FYM was composted and the slurry store was covered to minimise gaseous losses. However, after land application, inappropriate application method or timing would result in much larger ammonia losses from the slurry than from the FYM. Thus, it is necessary to consider the whole system when considering environmental impact.

Nitrogen
In an organic system it is especially important to minimise environmental losses because the N can be quite costly. For example, in a stockless system, cash crops have to be replaced by fertility building leys which provide no income for the 2-4 years in place. It is less straightforward to assign a cost to the fixed N in a mixed system because the grass/clover leys sustain the animals, as well as fixing N for the subsequent crops. Nevertheless, N in organic systems is more ‘hard-won’ and so it is especially important to retain it.

Our review focuses on the impacts of manure use. Although there are small differences in nutrient contents between conventionally produced and organically produced manures, they are sufficiently similar such that much of what we know about N management practices to reduce N losses in conventional systems is directly transferable to organic systems. This is reflected in the Organic Standards which mirror much of the advice in the Air, Water and Soil Codes.

Therefore, with land-spreading, manure N can be retained by:
- applying manures with a large labile N fraction (e.g. slurries) in winter or spring when the risk of leaching losses has passed.
- rapidly incorporating such manures so as to reduce ammonia losses

However, this is not always common practice, with much of the manure being applied to the fertility building stage: with less scope for rapid incorporation, unless applied just before breaking the ley. However, if this is undertaken in the autumn, then there will be an increased risk of leaching if manure is applied to the ley.

Losses during housing occur predominantly as NH_3. For slurry based systems the advice is to:
- collect the urine and faeces from the houses regularly
- consider techniques that would reduce hydrolysis of the urea to ammonia (though some might be inappropriate for organic systems)

These techniques minimise ammonia losses from the house. In theory, with animal housing systems involving forced aeration (pigs and poultry). However, this technology is likely to be inappropriate for organic livestock because the Standards specify natural ventilation and access to outdoors.

Advice for decreasing losses from slurry storage is simple:
- cover the slurry store (or allow it to crust)
- do not agitate unnecessarily.

It is this latter point that is perhaps the most contentious, because ‘aeration’ is a recommended practice for slurry treatment. The literature clearly shows the theoretical benefits of effective aeration, but also accepts that this is prohibitively expensive. Then, the risks of not doing a thorough job are increased gaseous losses of N.

Although most farms will have some slurry to deal with, organic systems encourage production of FYM, for both cattle and pigs. Our review shows that the challenge with these manures is not so much that of retaining N after land application or, indeed, during housing: rather, retaining N in the system during manure storage. Our conclusion is that application of straw to the housing will reduce ammonia losses, and the greater the amount of straw the smaller the losses of ammonia during housing. This is because the straw absorbs urine.

However, the resultant FYM is at risk of large volatilisation losses, and this can be exacerbated by regular turning, heating up and moisture loss associated with composting. Various management options have been tried to reduce losses. At the moment, the main management options for decreasing N losses during storage are:
- use as much straw as possible
- cover the manure heap

The simplest tool is to use sufficient straw to raise the starting C:N ratio of the FYM to 25-30. This offers ideal conditions for rapid immobilisation of the N, thus minimising volatilisation losses. However, straw could well be limiting in an organic system. Again the additional costs of purchasing straw have to be offset against any financial benefit achieved by capturing the N. Although this needs a more detailed financial assessment, it is our feeling that the straw costs would outweigh any increased fertiliser value, especially as the N would be immobilised into slow-release forms.

Loose covering of manure heaps has not shown any benefit in terms of decreased ammonia losses - and can increase losses if the heap dries out. Covering heaps is advocated, but moreso for retention of nutrients that would otherwise be washed out (see later). The literature does not include mention of tight covers, which might reduce air exchange. UK experiments are assessing this technique and so we await their conclusions.

It is perhaps manure storage, therefore, that needs most research to identify best practices for retaining N. There is also the need to consider the effects of other bedding materials, should straw become prohibitively expensive. The nature of the materials will clearly affect losses of N during housing and storage.

Much of the management focus has been on ammonia emission, since this is the largest N loss component from manure in general. We conclude that effects of changing from conventional to organic methods on nitrous oxide would be small in comparison with the potential size of effects on ammonia.

Phosphorus and potassium
The focus of the review has been N and methane. More detailed studies are underway on P and K cycling in organic systems. However, it is our observation from our limited studies that mixed systems offer scope for better management of P and K from manures. This is because the P and K can be transferred around the farm to areas of the rotation where they are most needed, thus generally avoiding build-up of P reserves in some fields, and depletion in others. This more effective use of P in particular would potentially reduce P losses from soils to water.

Methane
The literature on methane emissions is less abundant than for N studies, with all of the information based on conventional systems. The animal is the key component, obviously. A change to solid manure handling systems will increase emissions though, if composted, this may lessen the effect. Although of environmental importance there is no direct effect on the farm economics of methane emissions. Because much of the methane derives from the animal, reducing stocking densities on a farm will decrease methane emissions on a farm basis, but will not effect total national losses unless animal numbers are decreased.

Recommendations for future work

The review has highlighted specific areas where further knowledge is required.

7.3.1. Nutrient related issues

- economic assessment - whereas some methods for retaining N in the farming system might be expensive for conventional farms, the need to conserve a scarce and sometimes expensive nutrient (N) in organic systems might make them feasible for inclusion on organic farms (e.g. scrubbers in pig/poultry units, importing straw). An economic appraisal of the cost of N in organic systems is therefore warranted to set these decisions in context.
- fertility building crops - there is a need for better assessment of volatilisation losses from mulched, legume-rich swards. There is also the wider issue of better quantification of nutrient supply from fertility building crops.
- nutrient balances - our calculations show the importance of accounting for nutrient (especially N) losses when constructing balances to assess the sustainability of farming systems. There is a need to review nutrient budgeting approaches to provide a guide to the best approaches available. This is also important in view that much of the surplus will be in organic form, requiring careful interpretation of such surpluses.
- poultry and pig manure - there is a need to obtain nutrient (and metals) data for organically produced manures to provide information on 'typical' levels, and the effects of management practices on levels. This would compliment the data set already collected for cattle manures and assist in the construction for nutrient

and metal balances for such systems.

- dietary impact effects - N (and PK) excretion rates and partitioning between faeces and urine will be affected by diet. There is no information specifically available on the effects of an organic diet, but clearly this is important because N amounts and partitioning will greatly influence subsequent losses.
- gaseous losses from an organic system - whereas our data are best estimates of the effects of organic management, it would be worthwhile to make confirmatory measurements of losses.
- impacts of manure storage - the need for measurement is especially pertinent to solid manure storage since this was identified as a major N loss pathway. Although some work is in progress, there is a need for projects that will quantify losses and develop simple management techniques to decrease losses. This also includes the need to consider bedding materials other than straw. These studies need also to be extended to green waste composts.
- aeration of slurry - ammonia losses from agitated slurry can be large. The environmental impact of slurry aeration needs practical measurement, to ascertain whether there is a mid-way position that offers advantages to slurry properties with no or small disadvantage (or even advantage) to the environment. This is especially important since it is a recommended practice for organic farms.
- Computer models would appear to be the ideal method for drawing together the results of trials constructed under different circumstances and for making this information available in a readily understandable form. However, existing models are incomplete, particularly with regard to organic systems, and require further development before this goal is achieved. There is a particular danger of applying data from conventional systems to organic models since available nutrients are likely to be lower, microbial processes may occur more rapidly, crop yields are likely to be smaller and nutrient contents may be different.
- There is a need to make organic sector bodies and farmers more aware of the ammonia (and nitrous oxide) issue because it has been overshadowed by concern over nitrate. This is especially important in view of impending legislation relating to IPPC. It is also a more positive and more practical message that needs to be conveyed to the organic sector: i.e. the need to retain expensive N in the system, and the methods by which it can be done.

7.3.2. Other issues

- GMOs - ring-fencing of organic farms from GMO impacts will require (a) removal of the 20% conventional feed ration allowance, (b) exclusion of imported straw from GM crops and (c) exclusion of imported manure from non-organic herds fed on GM crops. There is therefore a need to investigate the effects of animal digestion and manure management practices on the survival of genetic material from GM feed to investigate if this stance is warranted.
- Pathogens - with concern over the likely transfer through the system of pathogens in sludges and manure, the need for work specific to organic systems is warranted because of differences in animal management and welfare practices, as well as the reliance of such systems on manures. This is especially pertinent to vegetable production systems.

It should also be acknowledged that there is considerable research on many aspects of manure management in conventional systems that is currently in progress and this will contribute to further understanding of manure use in organic systems. Results from this research therefore needs also to be interpreted in this light and an update of this review should be considered in 12-18 months time.

Technology Transfer

Project seminar

As a part of the project, a one-day seminar was organised at The Henry Doubleday Research Association (2 November). Invitations were sent to organic farmers with livestock enterprises, and over 100 delegates (excluding speakers) chose to attend. The objective of the day was to disseminate some of the information gathered during the project, but also to include the wider issues of manure management. The programme was as shown:

10.15	Welcome to HDRA	Margi Lennartsson (HDRA)
10.50	Manure use in organic farming	Mark Shepherd (ADAS)
10.30	Nutrient budgeting	Liz Stockdale (IACR)
11.10	Future environmental policy: implications for manure use	Ian Davidson (MAFF)
11.30	Future policy: manure use and standards	Francis Blake (SA)
11.50	Organic farming - the real world	Ed Goff
12.10 - 12.30	DISCUSSION	
12.30 - 14.00	LUNCH and posters	
14.00 - 15.30	Demonstrations:	
	- MANNER - manure use advisory model	Mark Shepherd (ADAS)
	- rapid field methods for manure analysis	John Williams (ADAS)
	- NPK budgets	Anne Bhogal (ADAS)
	- reducing NH_3 emissions	Brian Pain (IGER)
15.30	TEA AND DEPART	

Other outputs

- Poster presentation of project aims at the Cirencester Organic Farming Conference, January 1999 (500 delegates).
- Platform presentation ‘Manures in organic farming systems’ at the Society of Chemistry Industry meeting ‘Organic Farming: Implications for the Environment’, 23 March 1999 (100 delegates), with distribution of a 2 page summary and publication on the World Wide Web.
- Platform presentation ‘Cattle manure composition from organic farms’ to the Nutrients in Organic Agriculture Group (NOAG), (30 delegates) with publication of a summary on the World Wide Web.
- Inclusion of cattle manure analyses in Elm Farm Research Note, distributed to most organic farmers.
- Submission of a written paper for presentation at the British Grassland Society Winter Meeting (November 1999): SHEPHERD, M.A, BHOGAL, A., PHILIPPS, L., RAYNS, F., JACKSON, L. & PAIN, B. (1999). Manure Use In An Organic Mixed Farming System: Where Does The Nitrogen Go? *Proceedings of the British Grassland Society, ‘Accounting for Nutrients’*. pp. 163-164.
- Discussions with Soil Association about the implications of the review on standards (particularly in relation to N losses from manure and the metal contents of manures).

Future outputs

- Abstracts have been submitted to IFOAM and the European Grassland Federation for consideration for presentations at conferences in 2000.
- Two scientific papers are part-written, reporting data from the manure nutrient and metal analyses. Discussions are also taking place with Soil Use and Management about the inclusion of a general review paper on manures in organic farming.
- A leaflet was drafted and handed out at the HDRA Open day, described above. Discussions are taking place with the Soil Association, to see if this information could be incorporated into a manure technical note.

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