Final Report **Project UKPIR01**

Methods for Disposal or Processing of Waste Streams from Intensive Livestock Production in Scotland and Northern Ireland

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EXECUTIVE SUMMARY

UKPIR01: Methods for Disposal or Processing of Waste Streams from Intensive Livestock Production in Scotland and Northern Ireland, May 2005

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Background to research

The Integrated Pollution Prevention and Control Directive requires that operators must:

- use Best Available Techniques (BAT) to prevent or minimise pollution;
- avoid waste production, or where that is not possible recover waste and dispose of it appropriately;
- use energy efficiently;
- take measures to prevent accidents and limit their consequences;
- restore their site to a satisfactory state on cessation of operations.

The Directive covers a range of activities but most numerous in Northern Ireland are those for the intensive rearing of pigs and poultry. The greatest number of intensive livestock installations in Northern Ireland are involved in broiler production but there are also IPPC installations for egg production and pig rearing. A similar situation exists in Scotland.

In general land spreading has been used as a key disposal route for livestock manures from these installations, although in Scotland most broiler litter is burned for energy production. In Northern Ireland large quantities of broiler litter have been utilised in the production of mushroom compost.

Many freshwaters in Northern Ireland and some in Scotland are highly eutrophic and soils in many areas have high phosphate levels. Producers will in some cases be constrained by the amount of land available for spreading and alternative techniques for dealing with livestock manures will need to be employed.

Objectives of research

Four key tasks/objectives were identified:

Task 1: To characterise and quantify manure waste streams from intensive pig and poultry installations. In order to define the extent of the problem, reliable information of the quantity and nutrient content of broiler litter, layer manure and pig slurry had to be established, and where appropriate recommendations for revision of standard figures made.

Task 2: To review the environmental impact of current disposal practices, involving the identification of the key environmental issues and activity data for each current practice, including products arising from any down stream processing.

Task 3: Prepare an inventory of past and current research and techniques employed in other countries in Europe and further afield, with a focus on successful techniques.

Task 4: Identify alternative treatment method options with the greatest potential for Northern Ireland and Scotland, taking into account the structure of the sectors and environmental constraints in Northern Ireland and Scotland. Include economic and environmental aspects in the evaluation as well as the potential for disease dispersion.

Key findings and recommendations

Broiler litter

There was good evidence from the study that figures for nutrient output and quantity of broiler litter should be updated and a recommendation was made based of the data obtained from the study. In Northern Ireland there is a real possibility that combustion as a biomass fuel can deal with surpluses in the medium term with appropriate investment in either a number of small combustion plants or a large centralised power generation plant. A recommendation was made that combustion of broiler litter is adopted as an alternative utilisation for almost all surplus litter produced in Northern Ireland, as is currently the case in Scotland. Mushroom compost manufacture was also an important alternative utilisation route.

Layer manure

Clear differences from previous standard figures for nutrient content and quantity were not apparent, and no recommendation for change has been made. Management options aimed at producing drier manure should be implemented, as this would permit a greater range of alternative uses. Opportunities for composting should be actively pursued, but establishing markets for compost taking into account any legal constraints on the end use of the product would be a key element of this strategy. A recommendation was also made that opportunities for development of manure into a more saleable product are pursued, e.g. by pelletising and selling into value added markets outwith traditional agriculture.

Pig manure and slurry

There was significant variation in nutrient content of pig manure and no recommendation was made for changes to standard figures. As a result of IPPC, changes are currently being made to pig diets to reduce the nitrogen and phosphorus content of manures and slurry. A recommendation was made that more detailed studies of this aspect be undertaken in two or three years time to evaluate this benefit. A recommendation was made that best management practice and techniques such as solids liquid separation of slurries be implemented. Further reductions in phosphorus are possible as shown by the results from multi-stage processes, and more novel processing techniques such as phosphorus removal by precipitation should be further examined.

Key words: Integrated pollution prevention and control; IPPC; pig; poultry; manure; broiler litter; slurry; disposal; alternative; utilisation; combustion; composting; biofuel; environmental; aspect; impact; intensive livestock production; land spreading; land bank; nitrogen; phosphorus; nutrients; eutrophication

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

1.1. Background

The introduction of Integrated Pollution Prevention and Control (IPPC) in the pig and poultry sectors has highlighted problems associated with utilisation or disposal of slurry manure and litter in Scotland and Northern Ireland. A significant proportion of the litter, manure and slurry from the IPPC livestock sector is utilised by land spreading at the moment, but pollution can occur if there is insufficient land resource and manure is applied inappropriately. Many fresh waters in Northern Ireland and some in Scotland are eutrophic or even hypertrophic, and soils in many areas have accumulated high phosphate levels, particularly in Northern Ireland. To prevent pollution and to comply with the requirements of the IPPC Directive limits on nutrients applied to land have been established. For IPPC permitted farms these are set out in Standard Farming Installation Rules (SFIRs). Initial experience of the permitting process gained in Northern Ireland has shown that as a result of environmental pressures, many farms are likely to encounter difficulties if land spreading manure. The situation is exacerbated by competition for land resources from other agricultural sectors not regulated by IPPC, but who are also coming under pressure as a result of controls on nitrate and phosphate use.

In order that the pig and poultry sectors can meet future demand for their products in a sustainable manner, they need to find alternative uses or treatments for slurry, manure and litter. Any alternative utilisation must result in a reduction of excess nutrients polluting soil and watercourses.

1.2. Scope - Waste streams from intensive agriculture

This report details the findings of a study to identify methods for disposal or processing of waste streams from intensive livestock rearing farms in Scotland and Northern Ireland that are permitted under either the Pollution Prevention and Control Regulations (Northern Ireland) 2003 or the Pollution prevention and Control Regulations (Scotland) 2000. For the purposes of this report 'waste streams' are taken to be slurry, manure or litter from pigs, laying hens and broiler chickens. Other waste streams are not considered in this study.

1.3. Overview of project tasks

1.3.1. Task 1

Farming practices have changed over the years and quoted 'standard' figures for manure production appear to be dated compared to current practice in some of the sectors, broiler production in particular. Task 1 has been concerned with gathering data from recent research and from farms to establish reliable estimates of the quantity and nutrient content of slurry/manure/litter produced with particular emphasis on the broiler industry where the greatest changes are thought to have occurred.

1.3.2. Task 2

Task 2 is concerned with identifying key environmental impacts from current disposal practices and activities including any products arising from down stream processing.

1.3.3. Task 3

Task 3 is a review of past and current research into disposal and treatment options for slurry/manure/litter in Europe and other relevant countries with emphasis given to techniques that are or have the potential to be successful.

1.3.4. Task 4

This task involves an appraisal of those techniques or combination of techniques identified in Task 3 above that have the greatest potential for alleviating the disposal problem in Northern Ireland and Scotland. In reviewing the options consideration has been given to environmental, economic and disease dispersion aspects.

2. CHARACTERISATION AND QUANTIFICATION OF WASTE STREAMS FROM INTENSIVE PIG AND POULTRY INSTALLATIONS - TASK 1

2.1. Background

There is evidence that recent data, some obtained from case study work examining farming specific IPPC application procedures, show that the quantity of manure produced by some of the intensive livestock sectors, in particular broilers, has reduced over the years. Industry practices have improved and moisture content of litter and manure has decreased. There appear to be discrepancies between some estimates associated with 'best industry practice' and evidence available from research and standard figures used in codes of good practice. The aim of task 1 is to establish more clearly the evidence for, and the extent of any required change.

2.2. Literature and unpublished information

From unpublished data from the recent system studies (Defra contract WA0632), and metal and nutrient balance studies at ADAS Gleadthorpe and ADAS Terrington (Defra contracts SP0119; SP0129) the following data are available. These latter studies covered laying hens and broilers at Gleadthorpe, and weaners and finishing pigs at Terrington.

Though the research data summarised below (Tables 2.2 – 2.5) were collated from experiments which have included the major components for nutrient balance, they allow a comparison of the measured or estimated manure output with the "standard" guideline estimate for the livestock class. In some cases, the model contributing towards the derivation of the standard has been applied to the live weight category, water and feed intake and an estimate of manure output (and N output) compared with the measurement.

Also, some sampling of litter output and analysis from commercial broiler and other poultry units has been undertaken in the past. Example results are shown in Table 2.1, for a broiler unit in Herefordshire. Quadrat (0.5m x 0.5m, area) samples of litter were collected and weighed, with a litter sample analysed for dry matter content. The data shown in Table 2.1 show relatively small variability, suggesting that the approach can give fairly consistent/reliable estimates of litter output and composition. In addition, two composite samples, each comprising five of the sub-samples were analysed for N components and other nutrients; the results taken together to allow estimates of total litter output (fresh and dry weight basis), N and other nutrient outputs. These estimates based on the litter sampling undertaken on the commercial unit in Herefordshire (Table 2.1), are summarised in Tables 2.4 and 2.5, showing data on poultry manure outputs and manure N outputs, respectively.

Table 2.1 Results of broiler litter sampling and weighing; Herefordshire 1998. K Smith, unpublished results

Sample No	Wt litter (kg)	DM g kg^{-1}	litter DM kg	Depth Litter (cm)
1	4.7	549	2.58	3
2	5.2	683	3.55	3
3	4.3	640	2.75	2.5
4	3.2	661	2.12	2
5	5.5	619	3.40	3
6	4	607	2.43	3.5
7	4.6	677	3.11	4
8	4.4	514	2.26	2.5
9	6.5	524	3.41	3.5
10	4.8	493	2.37	3
Mean	**4.7**	**596.7**	**2.80**	**3.0**
Median	**4.7**	**613.0**	**2.7**	**3.0**
St. dev	**0.9**	**71.2**	**0.5**	**0.6**

Initial inspection of the data (Tables 2.2 - 2.5) suggest that there are uncertainties associated with the standards used for both poultry and pigs; in particular, the standards for broiler manure (amount and N excretion) are consistently higher than indicated by these measurement data. This reflects the accumulation of anecdotal information over recent years and industry opinion.

Table 2.2 Comparison of estimated/measured manure outputs from recent research with current standards: pigs

Stock type and diet	Manure output			Predicted output		Comparison with		Source
	Measured Kg	DM adjusted kg	Daily (kg/pig/d)	Modelled (kg/pig/d)	Standards[4] (kg/pig/d)	Modelled %	Standards %	
Finishers[1]								ADAS Terrington
Winter 97/98	5540	4875	2.49		4.1		-39.3	Williams, 2001
Winter 98/99	3890	4551	2.32		4.1		-43.4	(Contract WA0632)
Mean winter	4715	4713	2.40		4.1		-41.3	
Summer 98	8030	3694	1.88		4.26		-55.8	
Summer 99	8190	5031	2.57		4.26		-39.7	
Mean summer	8105	4362	2.23		4.26		-47.7	
Growers[2]								ADAS Terrington, 1997
Diet A	75.1	67.1	1.06	1.12		-4.61		
Diet B	73.6	67.9	1.08	1.10		-1.77		Nicholson, 1998
Mean	74.3	67.5	1.07	1.11		-3.19		(Contract SP0119)
Finishers[2]								
Diet A	71.6	84.1	1.34	1.24		7.63		
Diet B	85.4	95.1	1.51	1.39		8.81		
Mean	78.5	89.6	1.42	1.31		8.22		
Weaner[3]								ADAS Terrington, 1998
With Zn	20.2	22.0	0.10	0.12		-12.77		
Exc Zn	15.2	15.9	0.08	0.12		-37.88		Nicholson, 2001
Mean	17.71	18.93	0.09	0.12		-25.32		(Contract SP0129)
Finisher[3]								
25%DM	281.9	273.1	3.90	3.28		18.85		
18%DM	417.9	352.4	5.03	3.42		47.13		
Mean	349.88	312.76	4.47	3.35		32.99		

Notes: [1] – Growing/finishing pigs, 10 weeks, ca 30-90kg LW, 28 pigs per group
[2] – Growing/finishing pigs, 3 weeks, 3 pigs in balance crates
[3] – Weaners, 6 pigs (6.5 – 25kg LW) in balance crates, 5 weeks; 3 finisher pigs (35 – 90kg LW), 10 weeks in crates
[4] – Comparison with estimates adapted from "standards" where further data on feed inputs required

Table 2.3 Comparison of estimated/measured excretal N and P outputs from recent research with current standards: pigs

Stock type and diet	Measured manure output (g/pig/d)		Predicted manure output (modelled or "standards")[4]		Comparison with modelling/standards %		Source
	Nitrogen	Phosphorus	Nitrogen (g/pig/d)	Phosphorus[5] (g/pig/d)	Nitrogen	Phosphorus[5]	
Finishers[1]							
Winter 97/98	26.6		28.7		-7.2		Williams, 2001
Winter 98/99	19.6		28.7		-31.9		
Mean winter	23.1		28.7		-19.5		
Summer 98	23.9		29.8		-19.7		
Summer 99	24.8		29.8		-16.7		
Mean summer	24.4		29.8		-18.2		
Growers[2]							
Diet A	21.0	2.5	23.4	7.4	-10.61	-66	Nicholson, 1998
Diet B	18.1	2.3	23.0	7.2	-21.65	-68	
Mean	19.5	2.4	23.2	7.3	-16.1	-67	
Finishers[2]							
Diet A	29.8	4.2	26.0	8.2	14.44	-49	
Diet B	32.9	4.6	29.1	9.2	12.81	-50	
Mean	31.3	4.4	27.6	8.7	13.6	-49	
Weaner[3]							
With Zn	4.4	0.84	5.0	1.6	-13.14	-47	Nicholson, 2001
Exc Zn	4.0	0.69	5.1	1.6	-22.47	-57	
Mean	4.2	0.76	5.1	1.6	-17.8	-52	
Finisher[3]							
25%DM	20.6	4.3	23.0	7.2	-10.55	-40	
18%DM	20.4	4.6	23.9	7.5	-14.70	-39	
Mean	20.5	4.5	23.5	7.3	-12.6	-40	

Notes: [1] – Growing/finishing pigs, 10 weeks, ca 30 - 50kg LW, 28 pigs per group
[2] – Finishing pigs, 3 weeks, 3 pigs in balance crates, ca 70 - 90kg LW
[3] – Weaners, 6 pigs (6.5 – 25kg LW) in balance crates, 5 weeks; 3 finisher pigs (35 – 90kg LW), 10 weeks in crates
[4] – Comparison with estimates adapted from "standards" where further data on feed inputs required
[5] – "Standards" for phosphorus are only estimated outputs, derived by extrapolation from the standards for N, using typical manure analysis

Table 2.4 Comparison of estimated/measured manure outputs from recent research with current standards: poultry

Stock type and diet	Manure output			Predicted output		Comparison with		Source
	Measured	DM adjusted	Per 1000 bird places (t/yr)	Modelled (t/yr/1000)	Standards (t/yr/1000)	Modelled %	Standards %	
Commercial unit (1991)[1]	27.9	26.9	13.52	14.67	16.5	-9.2	-18.1	Smith *et al*, 2000
Commercial unit (1998)[2]	24.8	24.7	7.32	16.57	16.5	-55.8	-55.6	K Smith, unpublished
Broilers[3]								
Diet 1	1417.3	1039.3	12.47		16.5		-24.41	ADAS Gleadthorpe
Diet 2	1480.2	1159.5	13.91		16.5		-15.67	Nicholson, 1998
Diet 3	1264.0	1053.3	12.64		16.5		-23.39	(Contract SP0119)
Diet 4	1293.8	1142.8	13.71		16.5		-16.88	
Broilers[4]								
A	508.7	340.0	11.82		16.5		-28.37	ADAS Gleadthorpe
B	516.1	320.0	11.12		16.5		-32.58	Nicholson, 2001
C	482.8	305.0	10.60		16.5		-35.74	(Contract SP0129)
D	391.2	281.7	9.79		16.5		-40.66	
E	421.1	306.7	10.66		16.5		-35.39	
F	429.3	288.3	10.02		16.5		-39.25	
Turkeys[5]								
1	1579.8	1566.7	43.57		46.4		-6.10	ADAS Gleadthorpe
2	1417.6	1290.0	35.87		46.4		-22.68	Nicholson, 2001
3	1918.5	1765.0	49.08		46.4		5.78	(Contract SP0129)
4	1597.1	1466.7	40.79		46.4		-12.10	
Mean	1628.2	1522.1	42.33		46.4		-8.77	
Layers[6] - study 1								
1	60.4	60.0	31.61		41		-22.90	ADAS Gleadthorpe
2	67.1	70.0	36.88		41		-10.05	Nicholson, 2001
3	75.8	70.0	36.88		41		-10.05	(Contract SP0129)
4	65.4	66.7	35.12		41		-14.33	
Layers[6] - study 2								
1	57.2	56.7	29.86		41		-27.18	
2	73.7	70.0	36.88		41		-10.05	
3	65.9	60.0	31.61		41		-22.90	
4	76.1	70.0	36.88		41		-10.05	

Notes: [1] – Commercial unit (1991), 12,840 broilers, 43 days, 2.15kg LW - checks on litter outputs; manure @ 57.8%DM; outputs in tonnes
[2] – Commercial unit (1998), 24,000 broilers, 39 days, checks on litter outputs; manure @ 59.7%DM; outputs in tonnes
[3] – As hatched birds fed on 4 commercial diets, 500 birds/pen, 49 day rearing period; 3 replicates per treatment
[4] – As hatched birds, 190 birds/pen, 42 day rearing period; 4 replicates per treatment
[5] – Male turkey flock fed on 4 commercial diets, 75 birds/pen, 20 week rearing period; 4 replicates per treatment
[6] – Four compound feeds to layer groups (384 birds each) over 21 days; 3 replicates of each treatment in 8 cages of 4 birds each

Table 2.5 Comparison of estimated/measured excretal N and P outputs from recent research with current standards: poultry

Stock type and diet	Manure output (per 1000 bird places kg/yr)		Predicted manure output (modelled or "standards")[4]		Comparison with modelling/standards %		Source
	Nitrogen	Phosphorus	Nitrogen (kg/yr/1000)	Phosphorus[6] (kg/yr/1000)	Nitrogen	Phosphorus[6]	
Commercial unit (1998)[1]	237.6		440		54		K Smith, unpublished
Broilers[2]							
Diet 1	331	101	495	180	-33.1		Diets include 4 phases:
Diet 2	457	113	495	180	-7.7		Starter, grower, finisher, withdrawal
Diet 3	407	91	495	180	-17.7		Nicholson, 1998
Diet 4	351	141	495	180	-29.0		
Broilers[3]				*Mean*	*-21.9*		
A	365	108	495	180	-26.3	-40.13	Diets include 4 phases:
B	362	104	495	180	-27.0	-42.06	starter, grower, finisher, withdrawal, with 6
C	362	101	495	180	-27.0	-43.99	supplementary additions of low, medium and high
D	320	90	495	180	-35.4	-49.79	Cu & Zn
E	386	94	495	180	-22.0	-47.86	Nicholson, 2001
F	334	87	495	180	-32.6	-51.72	
Turkeys[4]				*Mean*	*-28.4*	*-45.9*	
1	1385	537	1390	506	-0.4	--6.07	Four commercially available diets, with 5 stage
2	1093	331	1390	506	-21.4	-34.60	ration
3	1454	551	1390	506	4.6	8.82	Nicholson, 2001
4	1199	431	1390	506	-13.8	-14.81	
Layers[5] - study 1				*Mean*	*-7.7*	*-8.6*	
1	487	117	660	234	-26.2	-49.8	Four compound feeds
2	578	154	660	234	-12.4	-34.3	Nicholson, 2001
3	680	154	660	234	3.1	-34.0	
4	710	140	660	234	7.5	-40.3	
Layers[5] - study 2				*Mean*	*-7.0*	*-39.6*	
1	435	134	660	234	-34.1	-42.6	
2	489	149	660	234	-25.9	-36.5	
3	492	136	660	234	-25.4	-41.9	
4	576	135	660	234	-12.7	-42.4	
				Mean	*-24.6*	*-40.8*	

Notes: [1] – Commercial unit (1998), 24,000 broilers, 39 days, checks on litter outputs & N content; manure @ 32.2 kg/t N; outputs in kg N/1000 birds/year
[2] – As hatched birds fed on 4 commercial diets, 500 birds/pen, 49 day rearing period; 3 replicates per treatment
[3] – As hatched birds, 190 birds/pen, 42 day rearing period; 4 replicates per treatment
[4] – Male turkey flock fed on 4 commercial diets, 75 birds/pen, 20 week rearing period; 4 replicates per treatment
[5] – Four compound feeds to layer groups (384 birds each) over 21 days; 3 replicates of each treatment in 8 cages of 4 birds each
[6] – "Standards" for phosphorus are only estimated outputs, derived by extrapolation from the standards for N, using typical manure analysis

2.3. Sampling and analysis of litter and manure samples - research and consultancy data

The recently compiled Manure ANalysis DatabasE (MANDE) (Defra contract NT2006) covers the major poultry manure types, pig slurry and FYM, (as well as dairy and beef manures) and includes also information on storage and management. Samples of stored slurry, solid farm manures and dirty water (from cattle, pig, poultry and sheep units) were collected between April 2000 and December 2002, as part of a surveillance project measuring pathogen levels in farm manures (Food Standards Agency - FSA project BO5003).

Analysis of manures was by standard ADAS methods (Anon, 1986); manure pH and conductivity were measured in water, using methods adapted from those used for silage and soil analysis (Anon, 1986). The analytical results were compiled on an ACCESS database (MANDE), together with manure analysis data already held by ADAS from a previous survey of poultry manure in England and Wales (Nicholson *et al*., 1996). Substantial data collected within other Defra-funded research projects were also added, including those from MAFF contract OF0161 'The Environmental Impacts of Manure Use in Organic Agriculture' (Shepherd *et al.,* 1999). In total, the results of more than 800 manure samples were compiled in the database and these data were compared with previously reported "typical" analyses or standards (Anon., 2000; Chambers *et al.,* 2001a; 2001b).

The manure samples collected included the following manure types of relevance to SNIFFER UKPIR01:

- Pig FYM
- Pig slurry
- Poultry - broiler litter
- Poultry - layer manure

2.3.1. Pig manure

The mean, median, upper and lower 10%ile and range of pig FYM analysis collected are summarised in Table 2.6. There was good agreement between the mean pig FYM dry matter and total N concentrations compiled on the MANDE database and those previously reported (Anon., 2000; Chambers *et al.,* 2001a; 2001b). However, the mean total P_2O_5 concentration was 1.0 kg t^{-1} lower (~15%), and K_2O, SO_3 and MgO concentrations 2.9 kg t^{-1} (~60%), 1.6 kg t^{-1} (~ 90%) and 1.2 kg t^{-1} (~ 170%) higher than previously reported, respectively.

There was a weak relationship between pig FYM K_2O concentrations and dry matter content ($P < 0.05$; $r^2 = 13\%$), but there were no relationships for the other nutrients (N, P_2O_5, SO_3, MgO) with dry matter content, or between NH_4-N and total N concentrations. The NH_4-N content on average represented 19% of the total N content, although the range was large (0.2-59%). This figure was nearly double the previously quoted value for 'old' *i.e.* stored FYM of 10%. There was no relationship ($P > 0.05$) between the NH_4-N content expressed as a proportion of the total N content and manure dry matter. The mean, median, upper and lower 10%ile and range of pig slurry analysis data collected are summarised in Table 2.7.

Table 2.6 Pig FYM nutrient composition data

Variate	pH	DM	Org. C	Total N	Total P_2O_5	Total K_2O	Total SO_3	Total MgO	NH_4-N	NO_3-N	NH_4-N	NO_3-N	EC*
		(%)		(kg/t fresh weight – FW)							(% of total N)		(µS/cm)
Mean	7.9	26	32	7.2	6.0	7.9	3.4	1.9	1.3	< 0.1	19	0.6	3,542
Median	7.9	24	34	7.2	5.1	7.2	3.2	2.3	0.8	< 0.1	14	< 0.1	2,225
10 %ile	7.1	18	27	4.2	2.7	3.2	1.6	1.1	0.1	< 0.1	2.4	< 0.1	186
90 %ile	8.8	33	38	10	9.5	12	5.3	2.6	2.8	0.2	42	2.5	4,239
Min.	6.4	15	9	3.4	1.8	1.0	< 0.1	0.6	< 0.1	< 0.1	0.2	< 0.1	138
Max.	9.4	54	40	12	15	27	7.3	2.7	4.0	0.3	59	6.4	22,900
Sample No.	*39*	*39*	*35*	*39*	*39*	*39*	*35*	*13*	*39*	*35*	*39*	*35*	*34*
Previous mean value[a]	-	25	-	7.0	7.0	5.0	1.8	0.7	0.7	-	10	Nil	-

*EC = Electrical conductivity.
[a] Anon., 2000; Chambers *et al.,* 2001a; 2001b.

Table 2.7 Pig slurry nutrient composition data

Variate	pH	DM	Org. C	Total N	Total P_2O_5	Total K_2O	Total SO_3	Total MgO	NH_4-N	NO_3-N	NH_4-N	NO_3-N	EC*
		(%)		(kg/m^3)							(% of total N)		(µS/cm)
Mean	7.7	3.7	33	3.6	1.7	2.4	1.1	0.7	2.3	< 0.1	70	0.3	9,356
Median	7.7	2.2	34	3.2	1.0	2.0	1.3	0.7	2.0	< 0.1	76	< 0.1	11,500
10 %ile	7.1	0.8	22	1.6	0.2	1.3	0.2	< 0.1	1.2	< 0.1	42	< 0.1	745
90 %ile	8.4	11	41	6.0	4.3	3.8	2.0	1.6	3.8	< 0.1	89	1.2	16,700
Min.	6.3	0.4	16	0.7	0.1	0.5	0.1	< 0.1	0.2	< 0.1	20	< 0.1	270
Max.	8.8	18	45	9.0	9.0	7.4	2.1	2.0	5.3	0.1	100	1.4	25,700
Sample No.	*41*	*75*	*17*	*71*	*75*	*75*	*17*	*15*	*74*	*16*	*70*	*12*	*13*
Previous		2	-	3.0	1.0	2.0	0.5	0.3	0.5	Nil	60	Nil	-
Mean		4	-	4.0	2.0	2.5	0.7	0.4	1.2	Nil	60	Nil	-
Values[a]		6	-	5.0	3.0	3.0	0.9	0.5	1.8	Nil	60	Nil	-

EC = Electrical conductivity.
[a] Anon., 2000; Chambers *et al.,* 2001a; 2001b.

There was generally good agreement between the mean N, P_2O_5 and K_2O concentrations compiled on the MANDE database and those previously reported (Anon., 2000; Chambers *et al.,* 2001a; 2001b). However, SO_3 (*ca* 40%) and MgO concentrations (up to 2-fold) were higher than previously reported (Table 2.8).

Table 2.8 Pig slurry nutrient concentrations normalised to standard dry matter contents

DM (%)	Total N	Total P_2O_5	Total K_2O	Total SO_3	Total MgO
	(kg/m^3)				
2	3.0	1.0	2.0	0.7	0.4
4	3.6	1.8	2.4	1.0	0.7
6	4.4	2.6	2.8	1.2	1.0

Total N concentrations were strongly related (P < 0.001) to dry matter content (Figure 2.1). Similarly, P_2O_5, K_2O, SO_3 and MgO concentrations were related (P < 0.01) to dry matter content (Table 2.9). Also, NH_4-N concentrations were strongly related (P < 0.001) to total N (Figure 2.2) and, on average, represented 70% of total N compared with the previously quoted 'typical' figure of 60% (Anon., 2000; Chambers *et al.,* 2001a; 2001b), although the range was large (20-100%). Slurry NH_4-N concentrations expressed as a proportion of the total N content were inversely related to dry matter content (P < 0.001, r^2 = 41%; NH_4-N as a percent of total N = 81.1 – 3.03 x dry matter).

Table 2.9 Relationships between nutrient (kg/t) and dry matter content of pig slurry

Regression equation	Sample number	r^2 (%)	*P*
N = 2.12 + 0.39 DM	71	56	< 0.001
NH_4-N = 1.87 + 0.12 DM	74	20	< 0.001
P_2O_5 = 0.20 + 0.40 DM	75	71	< 0.001
K_2O = 1.75 + 0.17 DM	75	29	< 0.001
SO_3 = 0.46 + 0.12 DM	17	65	< 0.001
MgO = 0.03 + 0.18 DM	15	81	< 0.001

Figure 2.1 Relationship between pig slurry total N and dry matter content

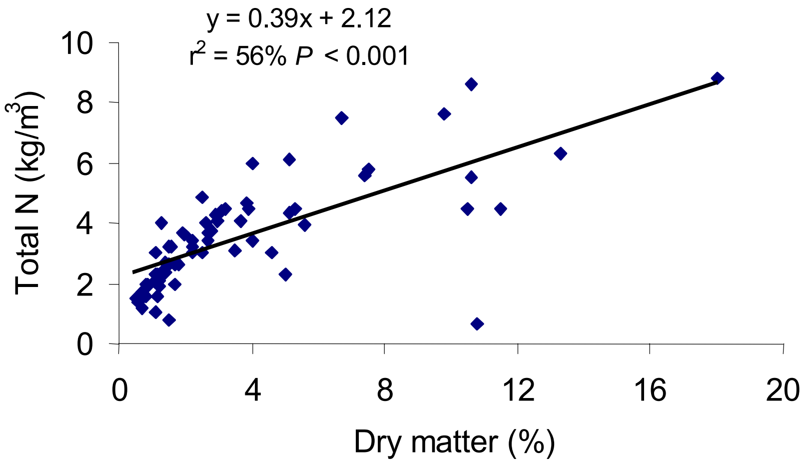


Figure 2.2 Relationship between pig slurry ammonium-N and total N

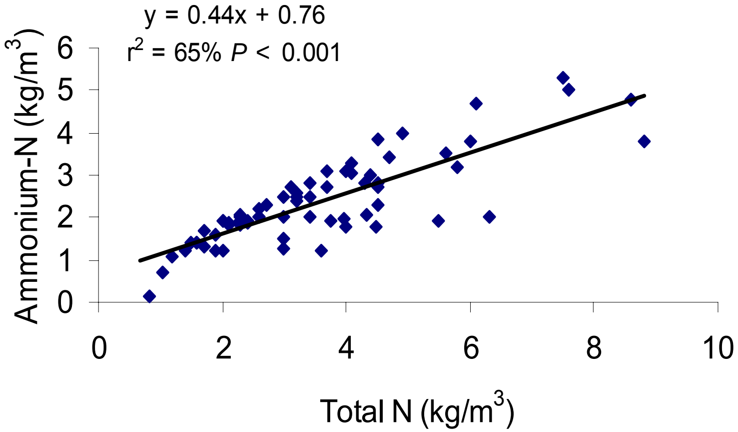


Table 2.10 Poultry layer manure nutrient composition data

Variate	pH	DM	Org. C	Total N	Total P_2O_5	Total K_2O	Total SO_3	Total MgO	NH_4-N	NO_3-N	Uric acid-N	EC*
		(%)					(kg/t fresh weight-FW)					(µS/cm)
Mean	7.8	35	28	19	14	9.5	4.0	2.7	6.0	< 0.1	3.0	8,016
Median	8.1	32	29	17	13	8.5	3.8	2.5	5.7	< 0.1	2.7	3,675
10 %ile	6.5	25	23	13	8.1	6.1	2.5	1.7	2.2	< 0.1	0.1	748
90 %ile	8.7	44	32	30	22	14	6.0	3.6	9.7	0.1	6.3	10,790
Min.	5.7	11	14	2.1	1.7	2.4	1.0	1.2	< 0.1	< 0.1	0.1	239
Max.	9.3	78	46	42	33	23	9.5	6.0	16	0.1	9.8	53,000
Sample No.	*87*	*95*	*87*	*95*	*87*	*87*	*86*	*88*	*95*	*11*	*84*	*10*
Previous mean value[a]	-	30	-	16	13	9	3.8	2.2	5.6	-	2.4	-

*EC = Electrical conductivity
[a] Anon., 2000; Chambers *et al.,* 2001a; 2001b.

2.3.2. Poultry manure

The mean, median, upper and lower 10%ile and range of poultry layer manure analyses are summarised in Table 2.10. As the MANDE database values were largely based on the same data (84 samples) as those previously reported by Nicholson *et al*. (1996), Anon. (2000) and Chambers *et al.* (2001a; 2001b), it is not surprising that there was good agreement between the two datasets when the nutrient concentrations were adjusted to a standard 30% dry matter content.

The mean, median, upper and lower 10%ile and range of poultry layer manure extractable N concentrations expressed as a proportion of the total N content are summarised in Table 2.11.

Table 2.11 Poultry layer manure extractable N as a proportion of total N

Variate	NH_4-N	NO_3-N (% of total N)	Uric acid-N
Mean	33	0.1	15
Median	31	< 0.1	13
10 %ile	12	< 0.1	0.7
90 %ile	58	0.4	37
Min.	0.5	< 0.1	0.4
Max.	73	0.4	50
Sample No.	*95*	*11*	*84*
Previous mean value[a]	35	-	15

[a] Anon., 2000; Chambers *et al.,* 2001a; 2001b.

The NH_4-N and uric acid-N concentrations on average represented 33 and 15% of the total N content, respectively. These values were in good agreement with the previously quoted figures for poultry layer manure of 35 and 15% of total N, respectively (Anon., 2000).

There was a weak relationship between layer manure total N concentrations and dry matter content (Figure 2.3). P_2O_5, K_2O, SO_3 and MgO concentrations were strongly related ($P < 0.001$) to dry matter content (Table 2.12). There was a weak relationship ($P < 0.01$) between uric acid-N concentrations and dry matter content, but no relationship ($P > 0.05$) between ammonium-N concentrations and dry matter. Also, there was a relationship ($P < 0.001$) between manure uric acid-N and total N concentrations, but no relationship ($P > 0.05$) between ammonium-N concentrations and total N. There was an inverse relationship ($P < 0.01$) between the NH_4-N content expressed as a proportion of total N content and dry matter content, but no relationship ($P > 0.05$) between uric acid-N content expressed as a proportion of total N content and dry matter.

Figure 2.3 Relationship between poultry layer manure total N and dry matter content

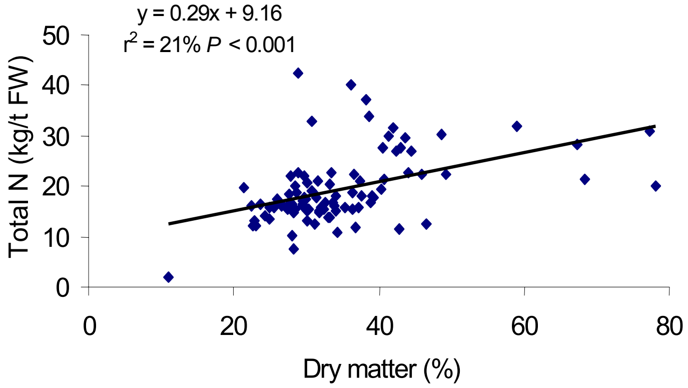


Table 2.12 Relationships between nutrient (kg/t) and dry matter content of poultry layer manure

Regression equation	Sample number	r^2 (%)	*P*
N = 9.16 + 0.29 DM	95	21	< 0.001
P_2O_5 = 2.63 + 0.33 DM	87	35	< 0.001
K_2O = 0.43 + 0.27 DM	87	58	< 0.001
SO_3 = 0.39 + 0.11 DM	86	62	< 0.001
MgO = -0.36 + 0.09 DM	88	68	< 0.001
Uric acid-N = -0.33 + 0.10 DM	84	9	< 0.01

The mean, median, upper and lower 10%ile and range of poultry litter (broiler and turkey) analysis data collected are summarised in Table 2.13.

Table 2.13 Poultry litter nutrient composition data

Variate	pH	DM	Org. C	Total N	Total P_2O_5	Total K_2O	Total SO_3	Total MgO	NH_4-N	NO_3-N	Uric acid-N	EC*
		(%)		(kg/t fresh weight-FW)								(µS/cm)
Mean	8.2	60	33	30	25	18	8.0	4.5	5.7	0.2	4.1	2,165
Median	8.3	60	35	32	25	17	7.0	4.4	5.7	0.1	3.3	1,980
10 %ile	7.1	44	26	18	16	11	5.2	3.2	2.6	< 0.1	0.5	476
90 %ile	8.9	77	38	43	31	24	12	5.9	8.7	0.4	7.8	4,003
Min.	6.4	36	18	12	12	9.0	4.1	2.2	1.0	< 0.1	0.2	431
Max.	9.3	87	40	57	52	30	14	9.5	10	0.4	15	4,270
Sample No.	*28*	*40*	*28*	*40*	*28*	*40*	*25*	*39*	*40*	*4*	*36*	*4*
Previous mean value[a]	-	60	-	30	25	18	8.3	4.2	7.5	-	4.5	-

*EC = Electrical conductivity.
[a] Anon., 2000; Chambers *et al.,* 2001a; 2001b.

As the MANDE database values were largely based on the same data (36 samples) as previously reported by Nicholson *et al.* (1996), Anon. (2000) and Chambers *et al.* (2001a; 2001b) the good agreement between the two datasets was as expected. The mean, median, upper and lower 10%ile and range of poultry litter extractable N concentrations expressed as a proportion of the total N content are summarised in Table 2.14. The NH_4-N and uric acid-N concentrations, on average, represented 20 and 13% of the total N content, respectively.
These values were in reasonably good agreement with the previously quoted values for poultry litter of 25 and 15% of total N, respectively (Anon., 2000).

Table 2.14 Poultry litter extractable N as a proportion of total N

Variate	NH_4-N	NO_3-N (% of total N)	Uric acid-N
Mean	20	1.2	13
Median	20	0.9	10
10 %ile	9.6	< 0.1	2.0
90 %ile	28	2.5	19
Min.	4.7	< 0.1	1.4
Max.	55	2.9	40
Sample No.	*40*	*4*	*36*
Previous mean value[a]	25	-	15

[a] Anon., 2000; Chambers *et al.,* 2001a; 2001b.

There was a strong relationship between broiler litter total N concentrations and dry matter content (Figure 2.4). Similarly, P_2O_5, K_2O, SO_3 and MgO concentrations were related to dry matter content (Table 2.15). There was no relationship (P > 0.05) between uric acid-N or NH_4-N concentrations and dry matter content, or between uric acid-N concentrations and total N. However, there were weak relationships between NH_4-N and total N (P < 0.05; r^2 = 11%) and between the NH_4-N content expressed as a proportion of the total N content (P < 0.001; r^2 = 29%) and dry matter.

Figure 2.4 Relationship between poultry litter total N and dry matter content

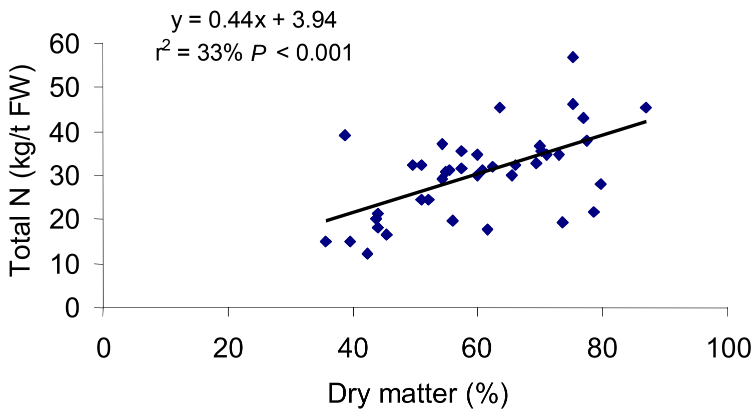


Table 2.15 Relationships between the nutrient (kg/t) and dry matter content of poultry litter

Regression equation	Sample number	r^2 (%)	*P*
N = 3.94 + 0.44 DM	40	33	< 0.001
P_2O_5 = 2.46 + 0.37 DM	28	38	< 0.001
K_2O = 6.34 + 0.19 DM	40	24	< 0.01
SO_3 = 0.54 + 0.14 DM	25	51	< 0.001
MgO = 0.60 + 0.06 DM	39	35	< 0.001

2.3.3. Comparisons with other “standards”

It is useful to compare the data on manure nutrient characteristics from within the current “SNIFFER” study, with those of the MANDE database and, also, more widely with similar relevant data from other European countries. While guide values for the composition of different types of manure exist in most central and northern European countries, such data is uncommon in most of south and eastern Europe. The method to derive such guide values also varies from country to country. While some are based on average values of analysed samples, others are derived from or verified with data on the nutrient excretion of different livestock categories and quantities of manure produced. The standard values for the composition of manure vary considerably between countries (Table 2.17). Part of this variability is due to differences in the production techniques (animal feeding, housing and storage systems, dilution of slurry etc.).

Both the averages and the range of the composition values for solid manure derived from the MATRESA (MAnure TREatment stratagies for Sustainable Agriculture) survey and that from the framework of RAMIRAN (Research Network on Recycling of Agricultural Municipal and Industrial Residues in Agriculture) (Menzi *et al*., 1998) are broadly similar and comparable to those data recorded from the recent MANDE database in England and Wales.

Table 2.16 'Typical' total nutrient contents for livestock manures (fresh weight basis)

Manure Type	DM	Nitrogen (N)	Phosphate (P_2O_5)	Potash (K_2O)	Sulphur (SO_3)	Magnesium (MgO)	Ammonium-N (NH_4-N)	Nitrate-N (NO_3-N)	Uric acid-N	NH_4-N	NO_3-N	Uric acid-N
	(%)					(kg/t)					(% of total N)	
Solid manures:												
Pig FYM	25	7.0	6.0	8.0	3.4	1.8	1.2	0.1	-	19	1	-
Duck FYM	25	6.5	5.5	7.5	2.6	1.2	1.3	0.2	-	21	3	<1
Layer manure	30	16	13	9.0	3.8	2.2	5.6	<0.1	2.4	35	<1	15
Broiler/turkey litter	60	30	25	18	8.0	4.2	7.5	0.2	4.5	25	<1	15
Slurries/liquids:						(kg/m^3)					(% of total N)	
Pig	2	3.0	1.0	2.0	0.7	0.4	2.2	trace	-	75	<1	-
	4	3.6	1.8	2.4	1.0	0.7	2.4	trace	-	69	<1	-
	6	4.4	2.6	2.8	1.2	1.0	2.6	trace	-	63	<1	-
Dirty water	0.5	0.5	0.1	1.0	0.1	0.1	0.3	trace	-	51	<1	-

The results from these studies indicate that, among other manure types, the 'typical' pig manure analysis data quoted in current advisory literature (*e.g.,* Anon., 2000; Chambers *et al.,* 2001a; 2001b) may benefit from revision. Some nutrient content values for manures produced on 'conventional' units are provided in Table 2.16.

Table 2.17 Average and range of composition values for different types of manure reported from different countries within the MATRESA project. RAMIRAN data after Menzi *et al*, 1998.

		Dry matter	N	NH_4-N	P_2O_5	K_2O	Mg
		g kg^{-1}					
Slurry						kg m^{-3}	
pigs	Average	51	4.8	3.5	2.0	3.2	0.6
	Range	15-92	1.2-8.2	1.9-6.1	0.3-5.0	0.6-8.0	0.1-1.8
poultry	Average	170	11.1	5.2	8.9	5.3	1.7
	Range	10-300	2-18	1.9-7.8	0.9-15	2.5-9.0	0.2-3.6
Solid manure						kg/t	
pigs	Average	243	6.9	2.2	5.6	6.5	1.6
	Range	150-330	3.5-11	0.5-6.0	1.7-15	2.8-16	0.9-2.5
poultry	Average	455	22.5	6.2	16.7	13.3	3.3
	Range	220-700	10-58	2.4-18	6.2-39	5.0-52	1.5-6.5
Solid manures RAMIRAN database						kg t^{-1}	
Pigs	Average	23.8	6.8	2.4	6.2	4.9	1.4
	range	20-30	4.0-9.0	0.7-6.0	1.9-9.2	2.5-7.2	0.5-2.5
Laying hens	Average	40.6	23.6	10.9	16.6	10.7	3.1
	range	22-55	5.1-25	37-60	8-27	6-15	1.2-6.0
Broilers	Average	60.3	24.5	8.0	18.5	17.1	4.2
	range	45-85	21.8-40	2.0-15	6.9-25	6.7-23	2.5-6.5

2.4. Quantities of litter and manure produced - data from commercial farms

Establishing the quantity of manure produced in large scale commercial farms can be difficult as the amount depends on a wide range of management and environmental factors, as well as the number, weight and diet of the animals or birds and any treatment, such as air drying. A sampling protocol was prepared to allow representative sampling of manure/litter from floor systems. This was similar to field sampling of soils in that it involved moving through the house in a 'W' shaped path and taking samples from a 0.5m × 0.5m area quadrat along the path. (Table 2.1 (above) illustrates results obtained using a similar method.) However the method was time consuming as a large number of samples had to be taken to obtain a representative result. This limited the number of farms that could be sampled. More accurate data would be obtained if all manure/litter could be weighed on approved weigh-bridges as it was removed from the houses. It proved possible to do this and thus obtain accurate value of quantities produced. Data for broilers is summarised in Tables 2.18 - 2.19. and for laying hens in Table 2.20. In Scotland data for layers was obtained from producers records (Table 2.21). Slurry sampling has been undertaken to determine nutrient content of pig slurry and data on quantities of pig manure and slurry produced have been obtained from previous research work detailed above.

Table 2.18 Quantities of broiler litter produced from commercial farms in Northern Ireland

Farm	Litter dry matter, %	Tonnes per crop	Birds placed	Tonnes litter per 1000 birds per crop
A	64.2	147.08	103005	1.43
B	68.4	91.34	81148	1.13
C	66.6	97.14	81431	1.19
D	61.7	131.9	79400	1.66
E	73.4	87.86	61900	1.42
F	67.1	157.4	113500	1.39
G	72.6	76.26	68000	1.12
H	66.5	82.88	68000	1.22
I	70.6	139.88	111429	1.26
J	65.4	398.24	268000	1.49
Mean	**67.65**			**1.33**
Standard deviation	**3.68**			**0.18**
Range	**61.7 - 73.4**			**1.12 - 1.66**

Table 2.19 Quantities of broiler litter produced from commercial farms in Scotland

Farm	Litter dry matter, %	Tonnes per cycle	Birds placed	Tonnes litter per 1000 birds per crop
A	68.3	85.36	116600	0.73
B	71.3	193.77	242800	0.80
C	64.9	366.6	265010	1.38
D	72.8	368.59	241560	1.53
E	71.2	423.88	241240	1.76
F	65.9	168.94	112940	1.50
G	69.4	290.41	178800	1.62
H	72.2	422.14	261100	1.62
I	69.2	222.41	242240	0.92
J	70.1	148.06	84000	1.76
K	71.2	112.81	90920	1.24
L	71.5	183.78	110500	1.66
M	71.1	365.83	217000	1.69
N	71.5	166.91	104330	1.60
O	67.9	108.53	71640	1.51
P	69.9	309.94	168910	1.83
Q	69.0	56.28	70770	0.80
R	68.7	364.31	230510	1.58
S	69.5	159.67	103000	1.55
T	70.2	196.00	153670	1.28
U	71.0	168.74	110030	1.53
V	69.5	138.81	89730	1.55
W	70.6	113.24	76510	1.48
X	68.9	139.14	156660	0.89
Y	65.7	302.73	206000	1.47
Mean	**69.7**			**1.41**
Standard Deviation	**2.0**			**0.33**
Range	**64.9 - 72.8**			**0.73 - 1.83**

Table 2.20 Quantities of layer manure produced from commercial caged layer houses in Northern Ireland

Farm	Manure type	Manure dry matter, %	Tonnes per week	Birds placed	Tonnes manure per 1000 birds per annum
A	Belt dried	45.50	9.55	23600	21.04
B	Belt dried	40.20	9.6	22500	22.19
C	Belt dried	36.30	19.38	40000	25.19
D	Belt dried	33.50	15.4	38000	21.07
E	Slurry	(not sampled)	45.01	38000	61.59
Mean		**38.9**			**22.37**
Standard Deviation					**1.95**
Range (belt dried)					**21.04 - 25.19**

Table 2.21 Producers estimated quantities of layer manure from commercial caged layer houses in Scotland

Farm	Manure type	Manure dry matter, %	Tonnes manure per 1000 birds per annum
A	Belt dried	60	22.0
B	Belt dried	60	21.5
C	Deep pit (ventilated)	60	23.5
D	Deep pit	35	38.0
Mean			**26.25**

2.5. Analysis of litter and manure samples from commercial farms

2.5.1. Sampling strategy

Collecting broiler litter samples for analysis involved moving down the length the house in a 'W' shaped path and taking samples along the path, a process not dissimilar for soil sampling in fields. Sub-samples were collected and then thoroughly mixed to provide a composite sample for analysis. Results are shown in Tables 2.22 - 2.23. With layers there are a number of different systems and different sampling methods have to be employed to obtain a representative sample. Caged systems are the most predominant followed by floor systems such as free range and barn. Where manure was dried on belts in caged systems sub-samples were collected directly from the belts after drying for a period of five or six days (belts are emptied approximately every seven days). The sub-samples were then mixed to provide composite samples for analysis. In deep pit systems sub - samples were taken from along the sides of the manure heaps after manure had been removed from the sheds, and then mixed to provide composite samples for analysis. A total of 29 slurry samples were taken from a number of pig farms in Northern Ireland at various stages of production. Results are shown in Tables 2.24 - 2.26 below.

Table 2.22 Nutrient analysis of broiler litter from commercial farms in Northern Ireland (fresh weight basis)

Sample	Dry matter, %	Total N, %	NH_4N, %	Total P (P_2O_5), %	Total K (K_2O), %
1	61.30	3.25	0.30	1.95	2.44
2	64.20	2.72	0.35	1.93	2.58
3	68.40	4.27	0.25	2.27	2.84
4	66.60	3.10	0.23	2.20	2.73
5	58.10	3.17	0.29	1.64	2.91
6	61.70	3.23	0.28	1.78	2.69
7	68.80	3.15	0.24	2.08	3.13
8	73.40	3.54	0.15	2.09	2.98
9	74.90	3.24	0.10	2.11	2.90
10	67.10	2.92	0.14	1.97	2.80
11	72.60	3.78	0.09	2.06	2.70
12	71.60	3.25	0.16	2.04	2.86
13	66.5	2.84	0.207	1.89	2.66
14	70.6	2.7	0.174	1.84	2.5
15	67.7	2.83	0.148	2.08	2.65
16	65.4	2.88	0.171	1.87	2.5
Mean	**67.43**	**3.18**	**0.21**	**1.99**	**2.74**
Standard Deviation	**4.63**	**0.41**	**0.08**	**0.16**	**0.19**
Range	**58.1 - 74.9**	**2.70 - 4.27**	**0.09 - 0.35**	**1.64 - 2.27**	**2.44 - 3.13**

Table 2.23 Nutrient analysis of broiler litter from commercial farms in Scotland (fresh weight basis)

Sample	Dry matter, %	Total N, %	NH_4N, %	Total P (P_2O_5), %	Total K (K_2O), %
1	69.90	2.88	0.18	2.45	2.07
2	68.30	3.08	0.18	2.32	1.96
3	72.00	2.95	0.17	2.49	2.05
4	69.30	2.93	0.18	2.49	2.01
5	69.80	2.85	0.19	2.61	2.07
6	68.40	2.98	0.21	2.41	1.99
7	76.20	3.13	0.14	2.45	1.93
8	72.20	3.08	0.14	2.33	1.82
9	72.90	3.09	0.16	2.34	1.83
10	77.00	3.14	0.18	2.65	2.07
11	77.70	3.16	0.12	2.64	2.03
12	78.70	3.21	0.14	2.67	2.06
13	75.90	3.43	0.15	2.49	2.07
14	77.30	3.38	0.16	2.60	2.16
15	73.80	3.17	0.16	2.50	2.04
16	80.20	3.27	0.12	2.43	1.88
17	81.80	3.75	0.12	2.51	1.95
18	79.30	3.29	0.12	2.51	1.89
Mean	**74.48**	**3.15**	**0.16**	**2.49**	**1.99**
Standard Deviation	**4.31**	**0.22**	**0.03**	**0.11**	**0.09**
Range	**68.3 - 81.8**	**2.85 - 3.75**	**0.12 - 0.21**	**2.32 - 2.67**	**1.82- 2.16**

Table 2.24 Nutrient analysis of layer manure from commercial farms in Northern Ireland (fresh weight basis)

Sample	Dry matter, %	Total N, %	NH_4 N, %	Total P (P_2O_5), %	Total K (K_2O), %
1	45.50	2.46	0.22	1.18	1.46
2	40.20	1.99	0.40	1.59	1.59
3	36.30	1.72	0.49	1.26	1.20
4	33.50	2.53	0.62	0.98	1.21
Mean	**38.88**	**2.18**	**0.43**	**1.25**	**1.37**
Standard Deviation	**5.20**	**0.39**	**0.17**	**0.25**	**0.19**
Range	**33.5 - 45.5**	**1.72 - 2.53**	**0.22 - 0.62**	**0.98 - 1.59**	**1.20 - 1.59**

Table 2.25 Nutrient analysis of layer manure from commercial farms in Scotland (fresh weight basis)

Sample	Dry matter, %	Total N, %	Total P (P_2O_5), %	Total K (K_2O), %
1	72.10	2.53	2.86	2.54
2	59.20	2.59	2.70	2.75
3	63.50	2.24	2.92	2.82
4	58.70	2.14	3.90	3.06
5	60.80	1.90	3.02	2.62
6	74.50	3.08	2.42	2.06
Mean	**64.80**	**2.41**	**2.97**	**2.64**
Standard Deviation	**6.84**	**0.41**	**0.50**	**0.34**
Range	**58.7 - 74.5**	**1.9 - 3.08**	**2.42 - 3.90**	**2.06 - 3.06**

Table 2.26 Nutrient analysis of pig slurry from commercial farms in Northern Ireland (adjusted to 4% dry matter)

Production stage	**NH_4 N, %** (adjusted to 4% DM)	**Total N, %** (adjusted to 4% DM)	**Total P (P_2O_5), %** (adjusted to 4% DM)	**Dry Matter %**
Dry sow	0.53	0.74	0.10	3.46
1st stage	0.49	0.59	0.08	3.44
2nd stage	0.48	0.74	0.36	3.77
Finisher	0.41	0.50	0.21	5.23
Mean (all data)	**0.47**	**0.63**	**0.18**	**3.88**
Standard deviation	**0.27**	**0.20**	**0.28**	**0.00**
Range	**0.07 – 1.13**	**0.17 – 2.35**	**0.02 – 1.55**	**0.8 – 9.9**

2.6. Comparison of data on quantities of manure from commercial farms with other data

2.6.1. Broilers

Comparison of the data obtained from commercial farms in this study lends support to the industry view that production techniques have improved and quantities of manure or litter produced are lower than previously published data. Litter production for broilers was very similar between Scotland and Northern Ireland at 1.41 tonnes 1000 birds^{-1} per cycle^{-1} in Scotland and 1.33 tonnes 1000 birds^{-1} per cycle^{-1} in Northern Ireland. Occupancy rates can also vary in length and this may account for some of the difference. In Northern Ireland growing cycles are usually 42 days whereas in Scotland there can be a greater proportion of birds being grown for a different market where the growing cycle is around 53 days.

In both Scotland and Northern Ireland the day old to day old period is typically 60 days therefore growers average approximately 6.0 growing cycles per annum (63% - 81% annual occupancy). This equates to litter production of 7.98 and 8.47 tonnes 1000 bird^{-1} places over an annual housing period (i.e. 6000 birds produced) for Northern Ireland and Scotland respectively. Improvements in litter quality are probably a significant contributory factor in the reduction. Mean dry matter content for litter in Northern Ireland was 67.4% and in Scotland it was 69.7% these values demonstrating that good litter quality is being achieved, irrespective of the age and type of housing. Bedding material was predominantly wood shavings although chopped straw was used on some farms.

2.6.2. Previous standard figures - broilers

Data on manure quantities can be presented in a variety of ways and this can make comparison difficult. Defra Fertiliser Recommendations for Agricultural and Horticultural Crops, RB209 seventh edition (2000) provides a figure of 17 tonnes output per annual housing period per 1000 broilers assuming an annual occupancy of 76% and a body weight of 2.2kg. Corrected for an occupancy of 63% (Northern Ireland Industry data) this equates to an annual housing period output per 1000 birds of 15 tonnes. This is well in excess of the 7.98 and 8.47 tonnes 1000 bird^{-1} places annum^{-1} recorded by weighing in this study. Other estimates can be obtained from codes of good agricultural practice. The DARD Code of Good Agricultural Practice for the Prevention of Pollution of water gives a figure of 60 litres per day per 1000 birds for litter at 60% dry matter. No density data is given in the DARD code or in RB209. However work by SAC gave density figures for settled litter as 0.6 t m^{-3}. Thus the DARD code equates to an output from housing of 8.3 tonnes per annum per 1000 bird places based on a 63% occupancy. This is close to the value obtained in this study. The Scottish Code of Good Agricultural Practice for the Prevention of Environmental Pollution From Agricultural Activity (PEPFAA) does not provide data on quantities for broilers.

Further comparison with data presented at Table 2.4 in the review section above emphasises the reduction in quantities produced by Northern Ireland and Scottish producers, although data gathered from a commercial unit in 1998 in the review was of the same order as the data gathered from commercial units in this study.

2.6.3. Laying hens

Determining quantities of manure produced by layers can be problematical due to the greater range of moisture contents in layer manure as a result of different systems incorporating different degrees of manure drying. In the UK, based on packing centre throughput during 2003, 69% of eggs were from cages, 25% free range (including 2% organic), and 6% barn. For IPPC installations BAT is to produce manure that is as dry as possible, either by drying on belts in cage housing, or ventilating manure pits in deep pit cage housing. Drying systems for free range and barn housing are not yet generally available, but these housing types tend to be below the IPPC threshold value. Quantities from cage systems with belt drying were assessed by weighing loads of manure over a weigh bridge immediately as it was removed during cleaning out. In Northern Ireland the value recorded was 22.37 tonnes 1000 birds^{-1} annum^{-1} at approximately 40% dry matter content. Scottish producers operating modern belt drying systems reported values of circa 22 tonnes 1000 birds^{-1} annum^{-1} at circa 60% dry matter content. Deep pit systems produced 25 – 35 tonnes manure 1000 birds^{-1} annum^{-1} at approximately 50% dry matter. These figures serve to highlight the variability incumbent in different layer systems. Despite increased use of drying systems, there appeared to be much variation in moisture content of layer manure. The figures above, taken from a relatively small sample of farms, are generally lower than the values of 30 - 37 tonnes 1000 birds^{-1} annum^{-1} reported by Nicholson (2001) in Table 2.4 above.

2.6.4. Previous standard figures - laying hens

Defra Fertiliser Recommendations for Agricultural and Horticultural Crops, RB209 seventh edition (2000) provides a figure of 41 tonnes per thousand birds per annum for 'undiluted excreta'. The DARD Code of Good Agricultural Practice for the Prevention of Pollution of Water states that a typical volume is 115 litres 1000 birds^{-1} day^{-1} for manure at 30% dry matter. At an assumed density of 1 litre kg^{-1} the value in the DARD water code is almost identical at 42 tonnes per thousand birds per annum. Two values are given in the Scottish PEPFAA Code of Good Practice, one at 115 litres 1000 birds^{-1} day^{-1} at 30% dry matter - identical to the DARD code, and a much lower value of 49 litres 1000 birds^{-1} day^{-1} for manure air dried to 70% dry matter. This lower value equates to 17.9 tonnes 1000 birds^{-1} annum^{-1} assuming a density of 1 litre per kg. Whilst the latest belt drying systems have the potential to dry manure to 70% dry matter or higher, the data collected in this study showed that this does not always happen in practice. A value of 25 - 30 tonnes 1000 birds^{-1} annum^{-1} at 50% dry matter would appear to represent a reasonable compromise within the range currently being achieved by the industry.

2.7. Comparison of data on nutrients in manure from commercial farms with other data

2.7.1. Broilers

Total nitrogen content (fresh weight basis) in Northern Ireland broiler litter samples was 3.18% at a dry matter content of 67%, in Scotland the figures were 3.15% at a dry matter of 74%. Corrected to 60% dry matter content and expressed as kg t^{-1} the values become 28.3 kg t^{-1} in Northern Ireland, and 25.4 kg t^{-1} in Scotland. These values are slightly lower than the 30 kg t^{-1} at 60% dry matter quoted in RB209 and the DARD Code of Good Agricultural Practice for the Prevention of Pollution of Water, but still within the range quoted in Table 2.13 above. Improved diets may be a possible reason for the reduction in N output. Expressed on a dry weight basis using the annual litter production figures recorded on commercial farms (from Tables 2.19 and 2.20, corrected to dry basis) 1000 broilers output over an annual housing period 255 kg total N in Northern Ireland and 267 kg total N in Scotland. These figures are in good agreement with those obtained by Smith (unpublished, 1998) for a commercial unit in 1998 in the ADAS Gleadthorpe study detailed in Table 2.5 above. They are almost 50% lower than the 495 kg per 1000 birds per annual housing period reported in RB209 (Anon, 2000).

Phosphorus is likely to be the limiting factor in many cases, particularly so in Northern Ireland. P_2O_5 content was 1.99% at 67% dry matter in Northern Ireland and 2.49% at 74% dry matter in Scotland. Corrected to 60% dry matter this equates to 17.7 kg t^{-1} and 20 kg t^{-1} for Northern Ireland and Scotland respectively. Again this is below the value of 25 kg t^{-1} at 60% dry matter given in RB209 and the DARD water code. Table 2.13 gives a mean of 25 kg t^{-1} and a range of 12 - 52 kg t^{-1} at 60% dry matter. The values recorded are therefore towards the lower end of the range (but it should be borne in mind that data in Table 2.13 includes turkey litter making direct comparison more difficult). Expressed on a dry weight basis using the annual litter production figures recorded on commercial farms (from Tables 2.19 and 2.20, corrected to dry basis) 1000 broilers output over an annual housing period159 kg total P_2O_5 in Northern Ireland and 210 kg total P_2O_5 in Scotland. The result shows an obvious difference between Scotland and Northern Ireland, it is not completely clear why this may be but dietary regimes were different on the farms sampled. In Scotland a wheat based diet was predominantly used and in Northern Ireland the digestive enzyme phytase was added to diets. It is possible that the addition of phytase could result in a difference of this order. It is also worth noting that all the broiler litter sampled from Scottish farms was being exported for incineration. The contract for this end use stipulates a minimum phosphorus content in the incinerated ash therefore lower P values are not as desirable as they would be if litter were being spread on land. Both values are much lower than the 435 kg per 1000 birds per annual housing period quoted in RB209. Notwithstanding this, there would be merit in undertaking further work outside this project to establish reasons for the differences.

Potash output over an annual housing period recorded in this study were 219 kg and 168 kg 1000 birds^{-1} (dry basis) for Northern Ireland and Scotland respectively. It is not apparent why there is a difference between the two countries. There was greater variation between the Northern Ireland samples but potash levels were generally higher. The value quoted in RB209 is 290 kg 1000 birds^{-1} annual housing period^{-1}.

2.7.2. Laying hens

Total nitrogen content (fresh weight basis) from layer manure samples was 2.18% at 39% dry matter for a belt system in Northern Ireland, and 2.41% at 65% dry matter for a deep pit system in Scotland. Corrected to 60% dry matter these values equate to 33.5 kg tonne^{-1} and 22.3 kg tonne^{-1}. These values are similar to or lower than the value in RB209 which gives a value of 16 kg t^{-1} total N at 30% dry matter (equivalent to 32 kg t^{-1} at 60% dry matter). The quantity of manure produced on commercial farms was lower (circa 25 tonnes 1000 birds^{-1} year^{-1}) and when corrected for dry matter resulted in an annual total nitrogen output of 545 kg 1000 birds^{-1} annum^{-1} in Northern Ireland and 601 kg 1000 birds^{-1} annum^{-1} in Scotland. The figure given in RB209 is 660 kg N 1000 birds^{-1} per annum^{-1}.

Phosphorus levels (P_2O_5) for laying hens were 1.25% at 39% dry matter in Northern Ireland and 2.97% at 65% dry matter in Scotland. Corrected to 60% dry matter this equates to 19.3 kg t^{-1} and 27.5 kg t^{-1} for Northern Ireland and Scotland respectively. This is similar to the value of 13 kg t^{-1} at 30% dry matter (equivalent to 26 kg at 60% dry matter) given in RB209 and the DARD water code. Table 2.17 above (RAMIRAN database) gives a mean of 24.54 kg t^{-1} at 60% dry matter and a range of 8 - 27 kg t^{-1} at 22% - 55% dry matter. The values recorded are therefore within or close to this range. Expressed on a dry weight basis and based on manure production of 25 t 1000 birds^{-1} annum^{-1} layers in Northern Ireland produce 313 kg 1000 birds^{-1} annum^{-1} of P_2O_5. In Scotland the figure was 742 kg 1000 birds^{-1} annum^{-1} of P_2O_5. The value for Scottish samples is significantly greater than the value of 545 kg 1000 birds^{-1} annum^{-1} quoted in RB209 whilst the Northern Ireland samples were lower. Some caution is required in interpreting these data as the sample size was limited. Further investigation from a larger sample size would be beneficial to determine the reasons for the differences between Northern Ireland and Scotland.

Potash output for laying hens recorded in this study were 341 kg 1000 birds^{-1} year^{-1} in Northern Ireland and 659 kg 1000 birds^{-1} year^{-1} in Scotland. A value of 360 kg 1000 birds^{-1} annum^{-1} is given in RB 209. Again there is no apparent reason why the Scottish data is much higher than the Northern Ireland figures.

2.7.3. Pigs

There was a lot of variation in manure nutrient content between the samples collected and this needs to be borne in mind when assessing the significance of the results. A few samples contained high levels of nitrogen and this resulted in the large range shown in Table 2.26. Averaged overall and corrected to 4% dry matter pig slurry total nitrogen contents were higher at 0.63% than the values of 0.36% given in Table 2.8 above, and the value of 0.4% given in RB209.

Phosphorus (P_2O_5) levels at 0.18% were identical to the data in Table 2.8 and slightly lower than the figure of 0.2% given in RB209.

2.8. Recommendations for change of 'standard' figures

2.8.1. Broilers

In this study good data was obtained for broilers, particularly with regard to quantities of manure produced as litter was weighed on removal from sheds. Although there were differences between Northern Ireland and Scotland these were small and a figure of 1.4 tonnes 1000 birds^{-1} cycle^{-1} would appear to be appropriate. At six cycles per annum this equates to 8.5 tonnes 1000 bird places^{-1} annum^{-1} at 70% dry matter. Nutrient data was obtained from a smaller sample size but the data was considered to be representative. Using the data collected in this study as the basis, it is recommended that the values in Table 2.26 be used when assessing nutrient output from broilers in Scotland and Northern Ireland. Data is presented as per production cycle and should be multiplied by the number of production cycles per annum that is actually being achieved. Different dietary regimes have been suggested as a reason for the differences between the two countries, particularly for P values, but further work to determine reasons for differences between Scotland and Northern Ireland would allow better refinement of the recommendations.

Table 2.27 Recommended 'standard' nutrient output from broiler production, Northern Ireland and Scotland

Livestock	Litter output, tonnes per cycle	Nitrogen, total N, kg per cycle	Phosphate (P_2O_5), kg per cycle	Potash (K_2O), kg per cycle
1000 broilers, Northern Ireland	1.4	45	27	37
1000 broilers, Scotland	1.4	45	35	28

2.8.2. Laying hens

A more limited data set was obtained for laying hens than for broilers so some caution is required when considering changes. It was evident that producers considered the quantities of manure they produce to be lower than those stated in RB209, due mostly to drying systems reducing the moisture content of manure. Data for Northern Ireland was obtained by weighing loads over a weigh bridge but data for Scotland was based on producers estimates and records. Data in the review also showed that quantities produced were lower than figures previously used. Whilst further work would be desirable to definitively establish any differences it does appear from the data in the review and from the limited data collected that a value of circa 25 tonnes 1000 birds^{-1} annum^{-1} (at approximately 50% dry matter) might be appropriate. This appears to be more representative of modern practice than the figure of 41 tonnes 1000 birds^{-1} annum^{-1} (at 30% dry matter) given in RB209 (Anon, 2000).

Regarding nutrients it was apparent that total N values, although slightly lower than the current RB209 value, were not so different to merit recommending a change particularly given the small sample size. There was a large difference in phosphate levels between Northern Ireland and Scotland with the RB209 value falling between the two values. The values recorded on commercial farms are also within the range of values identified in Section 2.3 above. There does not appear to be a need to suggest changes to the current values for P_2O_5 for laying hens. With potash the Northern Ireland data was similar to the current RB209 data whilst, as with phosphorus, the value recorded for Scottish farms was significantly higher. Given the limited sample size and reasonable agreement with existing advisory data, no recommendation is made for a change in the values used.

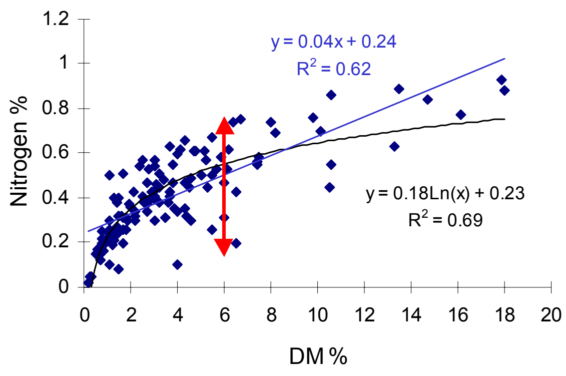
2.8.3. Pigs

A number of pig farms were sampled, (7 farms in Northern Ireland) and a large variation in the determined values was noted. Representative data was also obtained from literature review and the recently compiled MANDE, MATRESA and RAMIRAN databases described in Section 2.3 above. The variation in the level of nutrients found in pig slurry suggests that 'standard values' should at best only be used as indicative. The data does indicate that current advisory figures (Anon., 2000; Chambers *et al*., 2001a; 2001b) would benefit from revision. However, given the limited sample size (29 samples) and variability of data collected in this study no recommendation is made for a change in the 'standard' values. Notwithstanding this, it would be worthwhile reassessing standard figures in the future when farms are working to standard farming installation rules in order to ensure that standard figures can be used with confidence. Producers would benefit by having analysis done on their own farms as the variability in analysis encountered would not be anticipated on an individual farm.

2.8.4. Pig manure analysis

Probably as a result of a combination of high costs, generally long turn-round times for results and the difficulties of sampling, few farmers have manures analysed. Survey data (Smith *et al.,* 2001a) indicate that farmers prefer to take advice from published "standard" figures. Whilst the standard figures are very useful for general planning purposes (Chambers *et al*., 2001b), the variability behind these data need to be understood before they are applied in detailed fertiliser management planning. An example of the variation in pig slurry N content with dry matter is shown in Figure 2.5, (K Smith, unpublished data) in which the range about the "standard" N content of 5 kg m^{-3} at 6% dry matter is highlighted by the vertical arrow (*ca* 1.0 – 7.0 kg m^{-3}). This considerable range of N content, in slurry samples collected from commercial farms over a number of years, shows how misleading the standard value may be if applied without caution on a specific farm.

Figure 2.5 Variation in pig slurry N content with solids content; "standard" N content given at 0.5% for 6% dry matter slurry (Anon, 2000) but a range in N content (0.1% - 0. 7%approx) is shown by vertical arrow



Such variability in analysis of manures would not be anticipated on the individual farm, where animal diet, bedding use and manure management would be held fairly consistent and with the major source of variation attributable to dilution. Recent developments involving the use of portable equipment for the on-farm testing of slurries (Williams *et al.,*

1999) and in-line sensing techniques (Scotford *et al,* 1999) have shown impressive agreement with laboratory tests.
It can be seen, therefore, that an occasional laboratory analysis, supplemented by more regular checks using a portable slurry N meter or hydrometer (for dry matter), can provide a reliable and accurate strategy for gauging slurry nutrient application at the farm level.

3. ENVIRONMENTAL IMPACTS OF CURRENT DISPOSAL PRACTICES (TASK 2)

3.1. The manure problem in context

3.1.1. Estimating manure output

The degree of difficulty faced becomes apparent when stock numbers are examined along with quantities of manure and land required for spreading. Data on livestock numbers has been obtained from the 2003 DARD census, and the June 2004 Scottish Agricultural Census. Using data on manure quantity and nutrient content obtained in this study Tables 3.1 to 3.4 show the situation in Northern Ireland and Scotland respectively.

Table 3.1 Bird numbers and quantity of manure produced in this study, Northern Ireland

Livestock category	Livestock numbers, million *	Quantity of manure, t per annum (based on data from commercial farms and review in this study)	Quantity of manure, t per annum (calculated using Defra RB209 figures)
Breeding flock	2.5	62,500	102,500
Broilers (no. processed based on 6 cycles per annum, SNIFFER data, and 6.6 Defra data)	76.8	102,144	217,600
Layers (including free range)	2.2	55,000	90,200
Total		211,132	374,033

* = Taken from DARD Census June 2003 [Note at the time of writing 2004 census data was not available but preliminary announcements by DARD report that the Northern Ireland broiler flock has increased by 17%.]

Table 3.2 Bird numbers and quantity of manure produced in this study, Scotland

Livestock category	Livestock numbers, million *	Quantity of manure, t per annum (based on data from commercial farms and review in this study)	Quantity of manure, t per annum (calculated using Defra RB209 figures)
Breeding flock	1.3	32,500	53,300
Broilers (number processed based on 6 cycles per annum, SNIFFER data, and 6.6 Defra data)	64.3	90,793	182,230
Layers (including pullets being reared for laying)	3.8	95,000	155,800
Total		218,293	391,330

* = Taken from Scottish Agricultural Census June 2004

Table 3.3 Pig numbers and approximate quantity of manure produced in this study, Northern Ireland

Livestock category	Livestock numbers*, 000	Quantity of manure, t per annum (recent research data**)	Quantity of manure, t per annum (calculated using Defra and RB209 figures)
Breeding pigs (sows plus litter)	42.9	N/A	171,600
Pigs - fatteners (above 20 kg)	282.1	238,367	423,150

* 2003 census data
** from Table 2.2

Table 3.4 Pig numbers and quantity of manure produced in this study, Scotland

Livestock category	Livestock numbers*, 000	Quantity of manure, t per annum (recent research data**)	Quantity of manure, t per annum (calculated using Defra and RB209 figures)
Breeding pigs (sows & gilts in pig plus other sows)	48.9	N/A	195,600
Pigs – fatteners (20 ->80 kg)	280.7	237,235	421,140

* 2004 census data
** from Table 2.2

Improvements in the genetic potential of livestock and improved feeding efficiency, improvements in husbandry and greater attention to litter and manure quality, primarily to reduce ammonia emissions, may be responsible for the reduction in weight of manure produced. The data obtained in this study suggest that quantities of manure produced are likely to be lower than if current advisory literature on quantities were used. Whilst the lower quantities are desirable, the amount of manure produced needs to be considered with the nutrient composition and utilisation route. As an example if land spreading were the only option (using the litter analysis data obtained from commercial farms and the review in this study) to comply with a Nitrate Directive Requirement of 170 kg N ha^{-1} $annum^{-1}$ the minimum amount of suitable land for the pig and poultry sector would be as shown in Table 3.5.

Table 3.5. Theoretical minimum land requirement (170 kg ha^{-1} N limit)

	Land area (ha) required per 1000 bird places per annum, or per pig place	Minimum suitable land area Northern Ireland, ha	Minimum suitable land area Scotland, ha
Broilers	1.5	19,200	16,823
Layers	3.5	7,700	13,300
Breeders	4.5	11,250	5,850
Poultry totals		**38,150**	**35,973**
Sows*	0.13	5,555	6,333
Fatteners**	0.03	7,718	7,681
Pig totals		**13,273**	**14,014**

* manure output data from RB209
** manure output data from extrapolated from Table 2.2. Value of 2.32 kg pig^{-1} day^{-1} used

Based on 170 kg ha^{-1} N limit the theoretical minimum land requirements above for poultry comprise 4.2% of the total area of crops and grass in Northern Ireland and 2% of the area of crops and grass in Scotland. For pigs the proportions are 1.47% in Northern Ireland and 0.75% in Scotland. However a significant proportion of this land will be unsuitable for spreading organic manure for a variety of reasons (crop, slope, proximity to watercourses etc.) The problem is compounded when good practise advice is considered, this states that growers should aim to supply no more than 50% - 60% of the total nitrogen requirement of the crop requirement from organic manure. These factors will increase significantly the amount of land required. Difficulties are particularly acute in Northern Ireland where the majority of agricultural land (94%) is grassland. Much of this is unsuitable for organic manure application. Land not in agricultural use or in marginal or otherwise inappropriate use, e.g. upland areas, rough grazing, intensive horticultural production, is also unsuitable for manure application. In Northern Ireland agriculture covers 66% of the land area (CEH LCM2000, Land cover map) of which 83% is compatible for manure application (DARDNI, 2004), although only a very small proportion (ca 6%) is in arable cropping, which would be considered more suitable for receiving pig or poultry manures. Furthermore, potential disease problems in the poultry sector may limit transport of manure from time to time. These factors combine to further limit the amount of suitable land. The situation is less critical in Scotland where a greater proportion of the land is arable (34%) and therefore more suitable for manure application.

The above scenario illustrates the situation for nitrogen. In many cases phosphorus is likely to be the limiting factor rather than nitrogen. This is particularly the case in Northern Ireland where there are significant problems of eutrophication. Excessive soil P enrichment is acknowledged to be one of the major sources of diffuse pollution (Withers *et al.,* 2001) and to minimise this risk soil P status should be maintained at index 3 or less (Anon, 2000). According to DARD survey data, less than 10% of soils in Northern Ireland are at soil P index of 4 or above, but some 80% of Northern Ireland soils are at or above soil P index 2. Soils at P index 3 should receive P applications only at rates sufficient to replenish crop P offtakes; soils above index 3 should be discounted from manure applications. Having identified soils already high in P status, it is important that P applications in fertiliser and manures should be recorded and a balance kept, taking account of crop P removals. This will ensure that inputs are not allowed to greatly exceed crop off-takes. Average P off-takes range from 8 kg ha^{-1} yr^{-1} for upland sheep grazing, to 32 kg $ha^{-1}y^{-1}$ for grassland under intensive dairy production, with arable crops ranging 16-29 kg $ha^{-1}yr^{-1}$, in P off-take (Withers *et al*., 2001). It follows, therefore, that poultry litter supplying ca 46 kg ha^{-1} P should not be applied to the same field more often than 1 year in every 3 or 4 years depending on crop P offtake if soil P enrichment is to be avoided in the longer term. Similarly, pig slurry should not be applied at the 40 m^3 ha^{-1} rate more often than **approximately** one year in **three.**

In Scotland P analysis of soils is undertaken using a different method (Modified Morgans) and soil P values are classed as very low, low, moderate, high and excessively high. Soils at P index high (>30 mg l^{-1} extractable P, Modified Morgans method) should be discounted from manure applications. Studies have estimated that there has been a build up of P in Scottish soils (Paterson, 1994) and UK soils are over-supplied with P by an estimated 16 kg P ha^{-1} y^{-1} (Edwards and Withers 1998).

To ensure a good level of environmental protection the need for phosphorus inputs to be in accordance with crop requirements is reflected in the Standard Farming Installation Rules. The Northern Ireland rule requires that phosphorus shall only be applied to soils where there is a P requirement indicated by soil analysis and the fertiliser requirements in RB209. A phosphorus rule for Scotland is still under development.

Overall land requirement for pigs is also significant but it is more difficult to determine due to the different number of production systems in use incorporating different manure types (FYM, slurry). Although pig manure has a lower nutrient content than poultry manure the amount produced in Northern Ireland and Scotland is significant, requiring a large land bank for utilisation. It is also less easily transported resulting in potentially heavy application close to pig farms. Various studies have examined the relative proportions of FYM and slurry systems in pig production. Twenty years ago in Scotland Brownlie and Keith (1986a) suggested 70% slurry and 30% FYM. More recently Smith *et al* 2000 (manure management practice survey E & W) gave the proportions as 43% slurry 57% FYM. In 1997 Nicholson and Brewer suggested 44% FYM and 56% slurry. Clearly there are variations between the studies but over time the proportion of FYM based systems has increased, perhaps resulting from both environmental and animal welfare concerns. In Scotland 50%:50% slurry:FYM can be presumed, whereas in Northern Ireland approximately 95% of systems produce slurry (Mark Hawe, DARDNI, personal communication, 2005).

3.2. Current utilisation of poultry manure

3.2.1. Broilers

Information on current litter and manure utilisation routes was assessed by surveying the practices of key targeted sections of the industry. These tended to be the larger producers representing a sizeable proportion of their industry sector. Although this did not cover all producers the information gained was sufficient to give a good indication of the main uses litter and manure is put to. Based on information provided by the industry there were three main utilisation routes for broiler litter in Northern Ireland, these are shown below in Figure 3.2.

The situation for broilers is quite different in Scotland due to the existence of a dedicated poultry litter combustion facility based in Fife producing renewable energy under the Scottish Renewables order. This facility utilises almost all of the broiler litter produced in Scotland and can process 110,000 tonnes per annum, it therefore has the capacity to utilise all the poultry litter in Scotland. Based on information provided by growers it is estimated that only a small percentage, perhaps 10% or less of broiler litter in Scotland is spread on land.

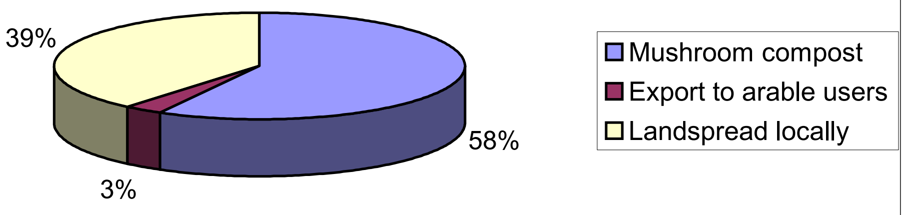


Figure 3.2 Estimate of current utilisation of broiler litter produced in Northern Ireland

3.2.2. Laying hens

The situation in both Northern Ireland and Scotland is similar in that virtually all laying hen manure is currently spread on land. Layer manure is wetter and does not contain bedding material and is therefore less suitable for combustion, at least without further processing or mixing with litter. Storage on the poultry farm after removal from housing is not common due to biosecurity issues but field storage prior to spreading is widespread. In Scotland, the concentration of laying farms in certain localities places significant demands on the land bank for spreading. In Northern Ireland there are approximately 60 large producers supplying eggs to around 10 packing stations. Given the reliance on land spreading, both IPPC and NVZ regulation will present significant challenges for egg producers.

3.2.3. Pigs

In both Scotland and Northern Ireland the majority of solid manure or slurry is spread on land in the vicinity of the pig farm. There is no easily accessible data on the amount of land being utilised for this purpose but the use is likely to be arable or grass leys. For convenience manure or slurry is often spread in close proximity to the pig farm resulting in increased pollution risks.

3.3. Aspects and impacts of current practice

The main environmental aspects and impacts of the current methods of using pig and poultry manure are summarised in Tables 3.6 – 3.8 below.

3.3.1. Utilisation by mushroom composting

Approximately 58% of broiler litter produced in Northern Ireland is utilised for mushroom compost. Using the 170 kg N ha^{-1} $annum^{-1}$ NVZ criteria, mushroom composting therefore reduces the land requirement by approximately 11,000 ha per annum. However this assumes that no spent mushroom compost is reapplied to land, and this is unlikely. Also, in many cases particularly in Northern Ireland phosphorus may be the limiting factor. The management of spent mushroom compost is an important aspect in the overall environmental impact of this utilisation route. Work undertaken by Teagasc (Maher *et al*, 2000) has shown that spent mushroom compost made from poultry litter and wheat straw has a nutrient content of 25 g kg^{-1} dry matter total nitrogen, 12.5 g kg^{-1} dry matter total phosphorus and 25 g kg^{-1} dry matter total potassium. Although these values are approximately half that of broiler litter, they are still significant having the potential to cause pollution when land spreading as an organic manure is the final disposal option. A total phosphorus content of 1.25% would make it difficult to justify the application of spent mushroom compost on some Northern Ireland soils. This disposal route diminishes the value of using poultry litter as a feedstock for mushroom compost as an ‘alternative’ to land spreading. Other options for spent compost such as a soil conditioner for the landscape industry or incineration could result in lower impacts to the soil and water environment and would be preferable alternatives. The composting process may also liberate significant quantities of ammonia and odours unless the emissions are controlled (by means of bio-filters or similar), this can negate the benefits of drying systems and attention to litter quality in order to reduce ammonia emissions during housing.

3.3.2. Utilisation by biomass combustion

In Scotland the majority of broiler litter is utilised by combustion. Litter is burned to produce renewable energy and the ash is used as a high value phosphorus and potassium rich organic fertiliser (Fibrophos). The fertiliser also has the benefit of containing secondary and trace elements.

The power station has the capacity to remove 110,000 tonnes of litter from the land bank each year and produce energy from renewable sources. The process is highly regulated to ensure that environmental impacts are minimised. The benefit of removing litter from the land bank for combustion would be negated somewhat if the fertiliser ash was returned to land inappropriately, but the product is supplied as a coarse powder and can therefore be easily transported to areas where the nutrient budget requires additional P and K to maintain soil fertility. There is a theoretical possibility of 'pollution swapping' when using combustion as opposed to land spreading as a utilisation route. Whilst ammonia emissions are likely to be greater when land spreading, products of combustion such as NO_x, SO_2 and particulates are emitted during combustion. However, in Europe the Waste Incineration Directive (WID) 2000/76/EC applies to combustion plant used for incinerating poultry litter. The WID requires exceptionally strict emission standards and this means that emissions from incineration will on balance have lesser environmental impacts than land spreading.

Incinerating poultry litter as a homogenous biomass fuel has many positive environmental impacts. Renewable energy is produced and consequently a quantity of fossil fuel is displaced, the burning of which would have higher emissions of SO_2 NO_x and particulate than poultry litter. A properly designed incineration plant will incorporate well contained and managed raw material storage areas so the risk of pollution from fugitive releases is lower than farm stores. The fuel stream is very homogenous so the risk of noxious emissions from contaminants in the fuel stock is essentially negated.

3.3.3. Utilisation by land spreading

It is undoubtedly the case that pig and poultry farms contribute to environmental problems resulting from inappropriate land spreading of manures, and this presents a major challenge. Notwithstanding this, their overall contribution to nutrient surpluses is not large in comparison with other industry sectors when considered on a national basis. Excessive inorganic fertiliser inputs and manure from cattle are likely to be one of the main causes of surpluses in both Scotland and Northern Ireland. One estimate (Jordan, C; DARD, personal communication) of overall manure loadings from pigs and poultry in Northern Ireland suggests that over all crops and grass (891,453 ha, year 2001), pigs contribute 2.58 kg ha^{-1} P_2O_5 and 2.75 kg ha^{-1} N; and poultry 7.84 kg ha^{-1} P_2O_5 and 7.39 kg ha^{-1} N. However, the data tends to mask the severity of the problem for pig and poultry producers who currently have no alternative to land spreading as a utilisation route. Distribution is a problem and excessive application on land close to large intensive units can result in significant impacts to soil nutrient status, and leaching of nutrients to watercourses and ground water. The situation is more acute in Northern Ireland as a result of high phosphorus levels in soils. An average loading does not take into consideration the suitability of land for spreading or local geographic concentrations of pig or poultry farms.

Pollution swapping can also be an issue with land spreading of manures. If nitrogen fertiliser is neither taken up by plants or lost by leaching, e.g. because this is minimised by use of buffer strips etc., it can end up being emitted as the powerful greenhouse gas nitrous oxide. It has been suggested that by limiting water pollution by nitrogen fertilisers a local problem could be swapped for the global problem of climate change (Reay, 2004).

3.4. Significance of environmental impacts

Tables 3.6 – 3.8 provide an overview of the aspects and impacts of each disposal route. As the material (the manure) is similar for each utilisation route there is a clearly a degree of synergy with the environmental aspects and impacts of the different utilisation routes.
It is therefore desirable to establish a measure of the significance of each impact for each route. In reality this would be done on a project specific basis but in a theoretical situation as is outlined in Tables 3.6 – 3.8, a generic type assessment can be made. A basic risk based approach has been used where both the probability of an aspect occurring and the environmental consequences of impacts has been assigned a value on a scale between +5 and –5. The two are added together to give an overall 'significance rating' between

+10 and –10. Values have been assigned after taking into consideration the adoption of best practice and current legislation that may impose limits in the process, e.g. the Waste Incineration Directive. Whilst this method may not allow an easy determination of whether an aspect or impact is significant in a practical situation, it will allow comparisons to be made between the main utilisation routes.

Table 3.6 Environmental aspects and impacts of litter/manure used for mushroom composting

Activities/Processes (Life Cycle Order)	Air Emissions	Releases to Water	Waste Management	Contamination of Land	Raw Materials, Natural Resources (Energy, Water etc.)	Local Issues (Noise, dust, odour etc.)
	Aspects(A)/Impacts(I)	Aspects(A)/Impacts(I)	Aspects(A)/Impacts(I)	Aspects(A)/Impacts(I)	Aspects(A)/Impacts(I)	Aspects(A)/Impacts(I)
Poultry litter/manure utilised for mushroom compost	(A) Gaseous emissions (NH_3, N_2O, H_2S, odours) from, stores, composting process and from land spreading spent material, also incineration of spent material. (I) • some are potent greenhouse gases; • acid deposition, - ammonia is particularly implicated; • changes in species composition of flora; • direct toxic effects, particularly to trees; • reduced biodiversity; • odour nuisance	(A) Effluent leakage from stores; surface run-off from yards. Diffuse pollution. (I) • point source nitrate pollution of watercourses; • diffuse pollution of ground water; • nitrate and phosphorus leaching from soils following spent compost disposal; • algal blooms; • increased BOD/COD, causing death of aquatic life; • increased suspended solids; • eutrophication; • reduced biodiversity; • reduced amenity.	(A) Integrity of stores & compost handling systems. (I) Impacts as for air, water and soil.	(A) Potentially toxic elements (PTE's) and excess nutrients in soil from spent compost application to land. (I) • build up of PTE's; • possible copper and zinc contamination; • possibility of other pathogenic contamination e.g. salmonella, *E.coli* O157; • nutrients (particularly N & P) leaching from soils into water.	(A) Energy and transport requirements for downstream processing systems. (I) • increased energy use for litter composting.	(A) All litter and compost handling operations. (I) • potential health risks to those handling litter e.g. *E.coli* O157, salmonella, when handling raw litter. • odour nuisance from composting process; • traffic nuisance (noise, litter & mud on roads, odour during transport etc.) • Nuisance dust when handling dry litter.
Significance score	-3	-2	0	-2	0	-1

Table 3.7 Environmental aspects and impacts of litter/manure combustion

Activities/Processes (Life Cycle Order)	Air Emissions	Releases to Water	Waste Management	Contamination of Land	Raw Materials, Natural Resources (Energy, Water etc.)	Local Issues (Noise, dust, odour etc.)
	Aspects(A)/Impacts(I)	Aspects(A)/Impacts(I)	Aspects(A)/Impacts(I)	Aspects(A)/Impacts(I)	Aspects(A)/Impacts(I)	Aspects(A)/Impacts(I)
Poultry litter/manure – combustion as a biomass fuel for energy generation.	(A) Gaseous emissions from stacks and also stores, (NO_x , SO_2, CO, CH_4, NH_3, N_2O, odours). Particulate emission. (I) • some are potent greenhouse gases; • acid deposition; • changes in species composition of flora; • reduced biodiversity; • odour nuisance • *Positive impact of displacement of greenhouse gasses from fossil fuel combustion*.	(A) Theoretical effluent leakage from storage areas; surface run-off from yards. Diffuse pollution from litter/manure/ash handling areas. (I) • point source nitrate pollution of watercourses; • diffuse pollution of ground water; • nitrate and phosphorus leaching; • algal blooms; • increased BOD/COD, causing death of aquatic life; • increased suspended solids; • eutrophication; • potential cryptosporidium contamination; • reduced biodiversity; • reduced amenity. • *Positive impact of reduced risk of nutrient leaching/diffuse pollution.*	(A) Minimal waste aspects assuming integrity of litter/manure/ash handling systems. (I) Potential impacts as for air, water and soil as a result of uncontrolled releases.	(A) Potentially toxic elements (PTE's) and excess nutrients in soil from inappropriate ash fertiliser application. (I) • build up of PTE's; • excess nutrients, particularly P & K leaching from soils into water if ash is used inappropriately. • *Positive impact of ash fertiliser correctly applied to maintain soil nutrient status.*	(A) Energy requirements for combustion process; potential layer manure drying; transport. (I) • potential increased energy requirement for manure drying; • energy for materials handling; • transport impacts • *Positive impact of renewable energy generation.*	(A) Noise dust and odour at the combustion facility. Increased traffic. (I) • potential health risks to those handling litter e.g. *E.coli* O157, salmonella. • odour nuisance; • traffic nuisance; • manure and mud on roads.
Significance	-2	+3	0	+3	+4	-1

NOTE: Positive scores are applied in this case as the probability of negative impacts is considered to be very low, for example due to stringent standards set by the Waste Incineration Directive

Table 3.8 Environmental aspects and impacts of land spreading litter/manure/slurry

Activities/Processes (Life Cycle Order)	Air Emissions	Releases to Water	Waste Management	Contamination of Land	Raw Materials, Natural Resources (Energy, Water etc.)	Local Issues (Noise, dust, odour etc.)
	Aspects(A)/Impacts(I)	Aspects(A)/Impacts(I)	Aspects(A)/Impacts(I)	Aspects(A)/Impacts(I)	Aspects(A)/Impacts(I)	Aspects(A)/Impacts(I)
Land spreading of slurry/litter/manure	(A) Gaseous emissions from field stores, and from land spreading (CH_4, NH_3, N_2O, H_2S, odours). Note: Slurries have greater impacts than solid manures. (I) • some are potent greenhouse gases; • acid deposition, - ammonia is particularly implicated; • changes in species composition of flora; • possible direct toxic effects, particularly to trees; • reduced biodiversity; • odour nuisance.	(A) Effluent leakage from field stores; surface run-off from fields. Diffuse pollution. Slurries more likely to pollute than solids. (I) • point source nitrate pollution of watercourses; • diffuse pollution of ground water; • nitrate and phosphorus leaching from soils; • algal blooms; • increased BOD/COD, causing death of aquatic life; • increased suspended solids; • eutrophication; • possible cryptosporidium contamination; • reduced biodiversity; • reduced amenity.	(A) Integrity of stores & manure handling systems. (I) Impacts as for air, water and soil.	(A) Potentially toxic elements (PTE's) and excess nutrients in soil from slurry/litter/manure application. (I) • build up of PTE's; • copper and zinc contamination from pig & poultry manure; • cryptosporidium contamination; • other pathogenic contamination e.g. salmonella, E.coli O157; botulism • excess nutrients, particularly N & P leaching from soils into water.	(A) Energy requirements for manure drying or energy and transport requirements for spreading operations. (I) • increase in energy use for manure drying (to reduce environmental impacts during housing).	(A) All manure handling operations. (I) • health risks e.g. *E.coli* O157, cryptosporidium, salmonella. • odour nuisance; • traffic nuisance; • manure and mud on roads; • dust when transporting dry litter.
Significance	-3	-5	-2	-4	0	-1

4. REVIEW OF CURRENT RESEARCH INTO DISPOSAL/TREATMENT METHODS FOR PIG AND POULTRY WASTES AND TECHNIQUES USED IN OTHER COUNTRIES – TASK 3

4.1. Introduction

When considering potential improvements in manure management and the applicability of research findings, it is important to understand the present manure management situation in those countries where relevant research has been undertaken.

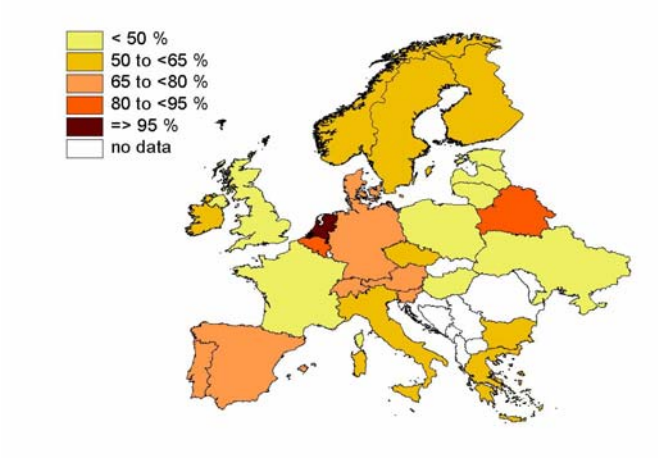
Hardly any countries have objective surveys of relevance. Past surveys on manure management systems, as undertaken in Scotland in 1974 and 1986 (Brownlie and Keith, 1986a and b), more recently in England and Wales (Smith *et al.,* 2000; Smith *et al.,* 2001a; Scott *et al.,* 2002) and in Switzerland (Menzi *et al.,* 2004), are notable among few exceptions. Some other useful information from across Europe has been gathered from consultants or researchers who are national "experts" on manure management. An overview was gathered through a survey using a questionnaire which was distributed to all participants of the recent MATRESA Accompanying Measure project (Burton and Turner, 2003); also to additional manure experts (especially in non-member countries of MATRESA). Data were received from 26 countries: Austria, Belgium (Flanders), Belorussia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Netherlands, Norway, Poland, Portugal, Russia, Slovenia, Spain, Sweden, Switzerland, UK, Ukraine. Thus the survey covered practically all of Europe except the Balkan states. Some additional information was taken from a survey on solid manure carried out by the working group on solid manure of the FAO, RAMIRAN network in 1997/98 (Menzi *et al.* 1998). The latter survey covered 16 countries: Austria, Belgium, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Italy, Netherlands, Northern Ireland, Norway, Portugal, Sweden, Switzerland and the UK.

The proportion of the total manure produced in the form of liquid manure/slurry and solid manure varies considerably between countries (Figure 4.1). It is highest in the Netherlands with around 95% and lowest, with below 20%, in some Eastern European countries like Ukraine, Estonia or Latvia. In general, the proportion of liquid manure/slurry is high (>65%) in most Central European countries and low in Eastern Europe, as well as the UK and France.

Pigs contribute more than half of the national manure production in Hungary and Denmark. In most other countries their contribution is 20-40%. Liquid manure systems are more common for pigs than for cattle in all countries. In S and W Europe (except UK) such systems are responsible for over 80% of the pig manure produced. Only in the UK, Norway and some Eastern European countries is the proportion of solid manure higher than 40%. Pigs contribute more than half of the slurry produced in Denmark and Hungary, but less than 10% in Ireland, the UK, Switzerland and the Ukraine.

For laying hens, liquid manure systems are practically non-existent in the UK, Germany, Switzerland, Denmark, Sweden and Lithuania, but are dominant in France, Spain, Ireland and Austria. For broilers and turkeys only solid manure is produced. Total production of poultry manures tends to be small compared to cattle and pig manures but can still be of great importance because of their relatively high nutrient content and, also, in terms of potential emissions to air or water.

Figure 4.1 Proportion manure from housed livestock produced as liquid (on a national basis)



4.1.1. Manure treatment systems in use

A wide range of treatment options already exists but, except for storage and mixing, as yet there is limited application of such technologies.

Mixing. Slurry in an unmixed store tends to separate into layers, with a sludge at the base (pig and cattle slurry), a low dry matter liquid and a high dry matter surface crust (in cattle slurry) formed by flotation of fibrous material associated with gas bubbles. This results in handling problems and uneven nutrient distribution. Mixing is straightforward now, especially since the development of powerful and efficient mixing systems and is now widely practised. Approaches available include fixed and mobile equipment powered by tractor take-off or electric motors. Some devices include maceration, to further enhance homogenisation and flow characteristics.

Separation. The mechanical separation of coarse slurry solids is practised to some extent in many countries, for example in Greece (for >90% of pig slurry), Spain (10% of slurry), Italy (15% of cattle and 40% of pig slurry), Netherlands and the UK. In addition, separation via settlement or sedimentation allows the reduction of suspended solids in slurries and effluents, for example in designed tanks, with overflows and baffles.

Aerobic treatment. Not commonly used anywhere at present though has been used in the past in the UK, to reduce odour nuisance, especially with pig slurries, and to aid mixing. There have been pilot schemes for the reduction and removal of excess nutrients in slurries, e.g. in the Brittany region in France and in the Netherlands, sometimes with the manipulation of aerobic treatment to facilitate nitrogen removal via nitrification/denitrification processes.

Anaerobic treatment. Anaerobic digestion with biogas production appears to be gaining in popularity, but possibly, largely as a result of government incentives in particular countries. For example more than 2000 such plants have been recently built in Germany, aided by a guaranteed premium for the electricity produced (Burton & Turner, 2003). In Denmark, since 1988, the government have provided economic incentives within biogas development programmes and, as a result, in 2001 over 20 centralised plants were in operation (Hjort-Gregersen, 2001). Large plants also exist in Poland and Italy, the latter with 5 centralised biogas plants and 67 farm plants in 1999 (Piccinini, 2004). The government incentives are clearly important, making biogas installations viable, particularly where the added benefits of odour, BOD and pathogen reduction and better flow characteristics are taken into account.

In the UK, in excess of 30 farm-scale digesters were known to exist in the late 1970s and early 1980s, but most of these have fallen into disrepair or no longer exist, although in Emyvale, Ireland a new plant is about to be commissioned (February 2005) to process duck slurry. In general, treatment is more common for pig slurry than for cattle slurry. The largest plants usually co-process wastes from the food processing industry; this allowing increased gas production or income through charges levied for the disposal of such material.

Composting systems. For solid manure, composting is the only treatment commonly practised, while in some areas, there is combustion in specialised power plants. Some large composting processes are in operation in France and Italy and in some S and E European countries. It is not always clear if an active treatment or just a natural degradation process during storage is implied as "composting". In the UK, the increasing costs and regulation of landfilling have stimulated increased interest in composting of non-agricultural wastes, sometimes involving on-farm operations encouraged by the gate fees associated with the disposal of these materials.

4.2. Research on manure management strategies

While few treatment systems have actually been adopted as part of current management practice across Europe (or elsewhere), research has continued to develop new technologies and has often demonstrated some measure of technical success. Because of the economic pressures facing the industry, emphasis in research (as well as in practice) has generally been on management solutions. However, the increasing regulatory pressures on farming may justify the increased costs of some treatment or component of treatment, where existing methods are not capable, by themselves, of adequately dealing with the environmental problems arising from livestock manures.

It is apparent from Section 3, that the 'land application route' cannot provide a universal solution for the dispersal of livestock manures sourced from units of intensive production in N. Ireland and Scotland. However, the adoption of best management practice can make an important contribution to diffuse pollution mitigation and is a key strategy requirement. 'Downstream measures' as a result of a particular land application strategy, will usually stand a good chance of being effective in reducing nutrient emissions. This is because there is relatively small chance of the benefit (in this case, conserved nutrients) being subsequently lost, as a result of additional uncontrolled losses following application of the abatement measure. This is in contrast to 'upstream measures' which may be applied in buildings or storage, and which may later be lost relatively easily, during subsequent manure handling or land application operations.

4.2.1. Manure Exports

Although an estimated 90 million tonnes of farm manures, annually, are applied to agricultural land in the UK (Williams *et al.,* 2001), with over 12 million ha of agricultural land, there is no overall problem with manure surpluses. However, in some areas there are high densities of animals, e.g. Yorkshire, as well as Northern Ireland, where there may be local surpluses of manure. Quite commonly also, there are large units of production with insufficient associated land area on which to safely recycle the manure production. In Scotland, in 1986, it was estimated that ca 21% of pig manures were transported onto other farms, and 56% of poultry manures (Brownlie and Keith, 1986). A recent study in England, found that whilst almost no cattle FYM or slurry was exported from the producing farm, some 29% FYM and 25% slurry was exported from pig farms and 69% of poultry manure from poultry units (Scott *et al.,* 2002).

This represents a practical and sensible arrangement between co-operating farmers and can be a successful way of dealing with local manure surpluses and, hence, of reducing the risks of environmental pollution.

Formal manure bank or farm waste brokerage schemes have been in operation in some countries, e.g. Netherlands, Denmark, Belgium and USA. An example was the Manure Agency East Netherlands (MBO) (Peirson, 1997). The MBO was a foundation set up in 1994 and run by a board of 7 appointees (including farmers). In 1993/94 they secured 4,000 contracts with farmers and 250 with contractors. Farmers and contractors joined on a voluntary basis but had to sign up for a minimum of 10 years. The original cost of setting up the MBO was 14 million guilders (ca £4m). This was raised via a joining fee, 25% of which was paid up front and used to set up the infrastructure. The remainder was to be paid on demand and would be used to run the organisation and provide finance for new and more expensive disposal options.

The MBO administered the disposal of manures to land and considered new disposal options. In addition to the registration fee, farmers paid a development or disposal fee. The MBO aimed to remove surplus manure and slurry and control the local market in order to keep prices stable and demand from arable farmers high. In total the MBO was responsible for 2.2 million tonnes of manure and had storage for 360,000 tonnes in arable areas, with 10% MBO ownership (the remainder owned by contractors). Within the catchment area of the scheme the MBO controlled 35% of the total manure/slurry produced. In the middle of the area, which was not adjacent to arable land 80 - 90% of the manure/slurry produced was controlled by the MBO. On the boundaries membership was only 15 - 20%. This is mainly due to the fact that the disposal fee was based on a flat rate, not taking account of distance from disposal areas. It was therefore more cost-effective for farmers on the outskirts to make their own arrangements, whereas farms located more than 12-15 miles from ‘disposal’ areas generally had greater problems with manure disposal and were more likely to use the scheme. Such schemes have ultimately failed in the Netherlands, largely as a result of costs. In areas where farmers needed to export manure, co-operating farmers (importing as well as exporting) inevitably found it cheaper and more convenient to make a private arrangement, with money exchanged only between the donor and recipient farms and no fee to the manure bureau.

More recently the Flemish Manure Bank has been set up as part of government strategy to deal with manure surpluses in Belgium (Anon, 2001). The prime aim is the transfer of manures from areas of surplus to areas of nutrient shortfall, where the manures can be beneficially recycled. In this role, the Manure Bank aims to bring the respective parties into contact but then allows the parties to determine the conditions of exchange/sale themselves. The Flemish Manure Bank depends entirely on government support, as it is part of an administration. All manure is transported by farmers or processed by the industry, with the Manure Bank controlling transport and production, but does not have an active role in the manure market (van Gijseghem, Vlaamse Landmaatschappij, personal communication). The Bank also acts as a ‘safety net’, where manures cannot be otherwise sold. In the latter case, the Bank takes responsibility for the manure, with the producer paying a levy.

In Scotland and N. Ireland, a number of factors seem likely to inhibit the development of a similar scheme including, importantly, the relatively low cost of purchased inorganic fertilisers, although with 34.5%N fertiliser recently at £160/t the situation is changing. Further perceived difficulties amongst farmers are the costs of manure applications and the uncertainties of quantifying the fertiliser value of organic manures. A range of reduced emission slurry application techniques have been developed (Huijsmans *et al.,* 1997), which have been shown to be effective in reducing gaseous ammonia emissions.

These are known, also, to provide a number of other benefits and may, therefore, reduce the negative perception of slurry amongst potential importing farms. These include improved application precision and better control of application rate. As a result of the improved control and partly as a result of slurry placement, potential for negative impacts (e.g., odour emissions, crop scorch, poor crop quality, nutrient loss in run-off) is reduced (Prins and Snijders, 1987; Laws *et al*., 2002). The costs of different techniques can vary considerably and, based on machinery costs and farm data from 8 European countries, Huijsmans *et al*., (2004) were able to estimate relative costs as follows, the range in costs taking into account the effect of farm size:

€3.7- 7.9.m^{-3} for trailing hose;
€3.9- 7.6.m^{-3} for trailing shoe;
€4.6- 8.6m^{-3} shallow injection;
€2.8- 5.1.m^{-3} for conventional surface broadcast application.

These estimates suggest an increase in the costs of slurry spreading over conventional surface broadcasting, of approximately 30-50%, 40-50% and 60-70%, for trailing hose, trailing shoe and shallow injection techniques, respectively.

The decision support system (DSS), SPReader Economic Assessment and Decision Support (SPREADS), capable of assessing the costs and associated performance characteristics of manure and slurry spreading techniques, was developed with Defra funding (project KT0101) (Gibbons *et al.,* 2003). Inputs are based on expert knowledge, published information and some field observations. The software allows the user to create, save and retrieve any number of spreading system designs and a large number of options can be rapidly tested. This facility allows the user to rapidly make informed choices about, not only the costs of possible new machinery or contractor spreading options, but also the time implications – e.g. are there likely to be enough dry days during the spring to undertake the necessary work?

Costs and work rates of spreading are very sensitive to several factors, which may vary considerably between farms and different locations. For farms that may need to consider the export and dispersion of manures on other land, distance to the receiving site is a key consideration. The SPREADS software has been used to evaluate costs and time requirements for two scenarios likely to be particularly affected by Integrated Pollution Prevention and Control (IPPC) legislation in Scotland and N. Ireland; a large pig finishing unit (3000 places) and a large broiler unit (100,000 birds). Estimated, annual, manure outputs (according to current "standards", Smith *et al.,* 2000) are 3990 m^3 (10000 m^3 after dilution by ca 2.5x giving slurry at a typical 4% dry matter) for the pig unit and 840 t broiler litter (data from Section 2). Potential financial (fertiliser replacement) values, based on "standard" nutrient content are shown in Table 4.1.

Table 4.1 Typical nutrient content and potential financial value of pig slurry and broiler litter (after Gibbs, 2004)[1]

Manure type	DM %	Total N kg t^{-1} or kg m^{-3}	NH_4-N	Uric acid-N	P_2O_5	K_2O	SO_3	Potential value[2] £ t^{-1} or £ m^{-3}
Pig slurry	4	3.6	2.4	na	1.7	2.4	1.0	1.90
Broiler litter	60	30	7.5	4.5	25	18	8.0	15.70

Notes: [1] Manure analysis database (Defra contract NT2006)

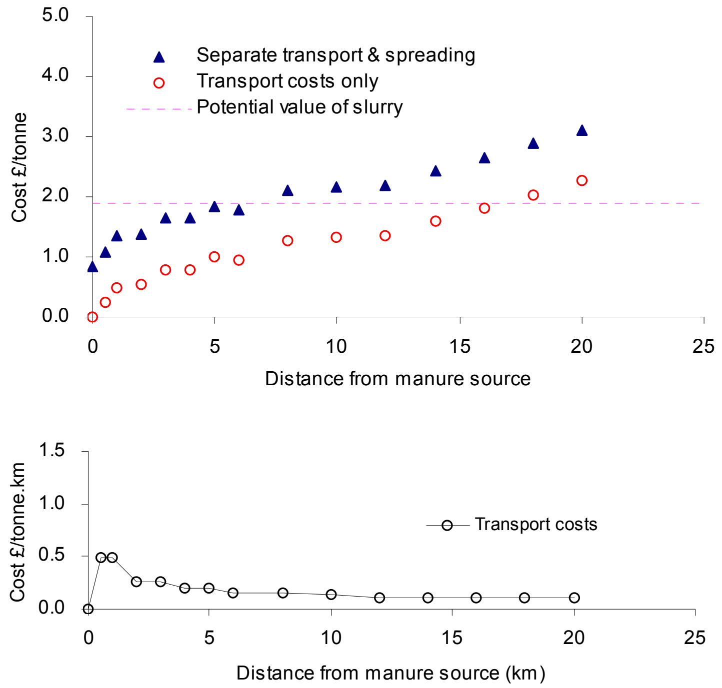
[2] Based on estimated readily available N and SO_3 content, total P_2O_5, total K_2O and recent fertiliser nutrient prices at 35p/kg N, 30p/kg P_2O_5, 20p/kg K_2O and 10p/kg SO_3.

The potential value of the dilute pig slurry, estimated at £1.90 m^{-3}, is sufficient to cover the transport and spreading costs up to ca 5 km and transport-only costs up to ca 16 km (Figure. 4.2a), although the receiving farm would not usually pay for slurry imports. Transport costs are heavily dependent upon tanker payload and travel time, so large tanker and fast tractor options, whilst increasing capital costs (14m^3 tanker ca £16,000 and tractor >£50,000), in this example have kept transport costs down. Initially, transport costs per m^3 km^{-1} are relatively high due to the speed restrictions along farm tracks and narrow roads, but then decreasing with distance and the higher speeds that are feasible on better roads (Figure 4.2b). The fast tractor can provide speeds of up to 40 km h^{-1}, but it is unrealistic to plan for such performance and more conservative figures are necessary to allow for traffic and road conditions, particularly over relatively short distances (Figure. 4.3).

Figure 4.2 Impact of distance on transport and spreading costs[1] of slurry from 3000 place pig unit

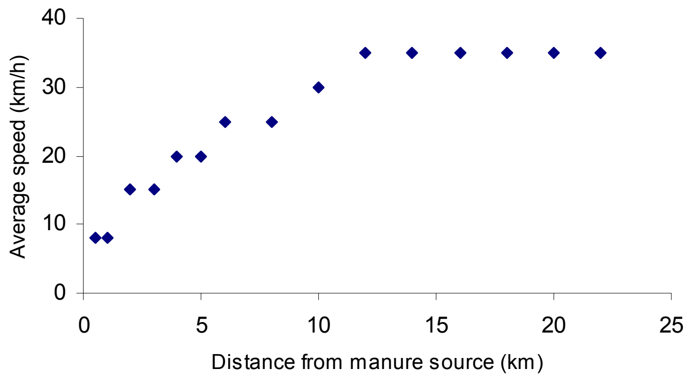
(a)

(b)



[1] Estimates made by "SPREADS"; transport and spreading with a 14m^3 tanker and fast tractor.

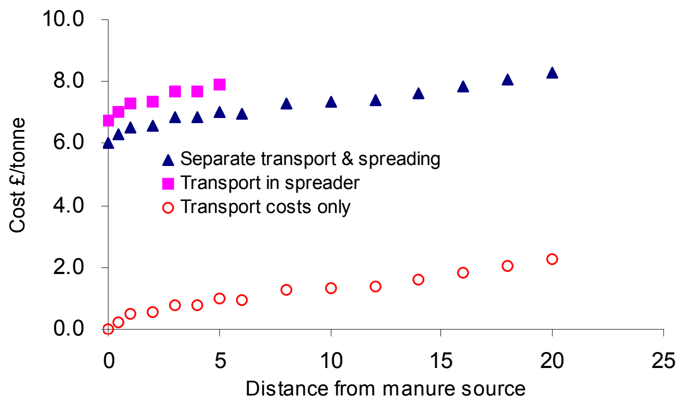
Figure 4.3 Impact of distance from farm and likely road conditions on average travelling speed; assumed speeds used to run SPREADS scenarios described above



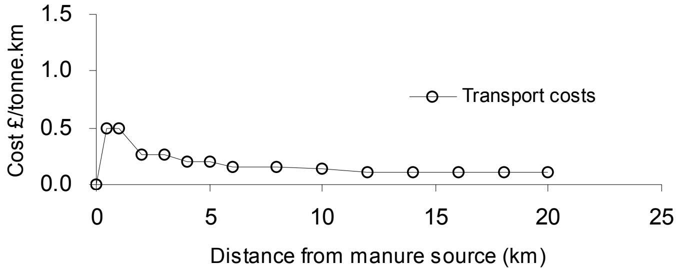
Poultry litter, with much lower water content and higher nutrient concentrations (Table 4.1), has much greater potential fertiliser replacement value (assuming application where the nutrients are required for crop production) and so, greater transport and spreading costs can be justified (Figure 4.4a). In the latter case, the systems costed include a 14 tonne road trailer with fast tractor, tipping onto a remote field, with subsequent loading and spreading using conventional farm loader and spreading equipment, with the field spreading costs included or excluded. The upper series of points in Figure 4.4(a) relate to the fairly common situation where litter is transported from the producer in the manure spreader, over shorter distances, the machine which also spreads on the receiving land. In these cases, the estimated costs are well within the potential fertiliser value, calculated at £15.70 t^{-1}. However, the costs as calculated in these examples are likely to be at the low end of the range, because of the choice of specialist equipment and assumed efficient operation. The fertiliser value of poultry manures are reflected in practice because there is a market for high dry matter poultry manure as a source of organic matter and fertiliser nutrients, particularly in the arable Eastern Counties of England where there are concentrations of poultry and turkey farms. Based on the data presented in Figure 4.4(a), it can be seen that the litter is offered to local cropping farmers at roughly the cost of transport.

Figure 4.4 Impact of distance on transport and spreading costs[1] of litter from a 100,000 place broiler unit

(a)



(b)



[1] Estimates made by "SPREADS"; road transport in trailer (14t) & fast tractor to field storage, with separate loader & spreader at receiving farm.

In the scoping study of Peirson (1997), comparisons of fertiliser value of manures with the estimated costs of transport and storage, suggested that slurry at 6% dry matter or less, had little net value over transport costs if hauled more than about one mile. The inclusion of any storage facilities, to allow slurry to be applied at appropriate stages of crop growth, would further reduce the net value of slurry. As above, the increased value of solid manures was noted, but only poultry manures were found to have any net value when hauled more than about 5 miles.

4.3. Manure treatment systems

4.3.1. Introduction

A wide range of treatment technologies is available, which can contribute to mitigation of potential pollution, some of the options being particularly effective for reduction of nutrients or BOD. Research has investigated how the technologies can best be applied, as well as attempting to develop new technologies. The chosen process should be an integral part of the manure management system at the farm and should be capable of meeting the clearly defined objectives of the system, which need to be identified before considering any treatment option. The benefits and drawbacks of the broad range of main treatment options are summarised in Table 4.2. (after Burton, 1997).

Technologies are available that can turn slurry into potable water, capable of discharge into a watercourse, but only at enormous cost. What are more certainly required are practical options that meet the needs of the problem without greatly exceeding these. So, partial treatment may be appropriate and inexpensive. "Treatments" also can be considered to include a number of "passive" options (e.g., settlement, storage, passive separation of solids via strainer facilities during storage, dilution), as well as the "active" options more typically regarded as treatment. The more important and relevant of these options are considered within this part of the review.

Table 4.2 Summary of main manure treatment options available on farms (after Burton, 1997)

Option	Benefits	Drawbacks	Comments
No Treatment (Direct land spreading**)**	Routine Task. Least cost. Avoids need for intensive spreading campaign	Regular task. Poor utilisation of nutrients. Risk of soil damage. Pollution risk.	Common option
Storage	Better nutrient utilisation by targeted spreading. Flexibility. Enables treatment options. Reduced viable pathogens.	Crusting and sedimentation problems. Capital costs. Increased odour potential.	Integral component of treatment processes.
Mechanical Separation	Reduces liquid volume. Reduces crusting and sedimentation in storage. Improved homogeneity of liquid. Easier pumping. Composting of fibre	Cost of pit, pump, gantry and separator. Operational costs. Reliability.	Important process for store management and crop utilisation. Used with biological treatment processes.
Aerobic treatment	Reduces odour and BOD. Provides mixing. Generates heat, which could be utilised.	Capital and operational costs. Separation necessary for most slurries. Selection of optimum system difficult.	Best option where environmental pollution is a risk, particularly odour.
Anaerobic digestion	Reduces odour and BOD. Biogas production. Easier handling of liquid. Pathogen kill.	High capital and operational costs. Management critical. Continuous gas' production requires use if benefits are not to be lost.	Continuous process. Attractive option where energy supply an issue.
Solid composting	Reduces odours. Saleable product. Can include other by-products.	Volatile emissions Capital and operational costs. Marketing skills required.	Very important to establish markets before following this route.

4.3.2. Storage

In order to gain maximum benefit from the nutrient content of manures and slurries for the fertiliser requirements of crops, particularly the nitrogen supply, manure applications should coincide with, or just in advance of, the period of maximum crop growth. This will also be the period of maximum nutrient uptake and will generally be in late spring. This implies the need for adequate storage to contain manures generated during times when spreading is undesirable or impossible due to adverse ground conditions (usually excessive wetness), or prohibited, for example as a result of the timing restrictions required by the proposed NVZ action programmes in Scotland and N Ireland.

Total store size will depend upon the required storage time, the number and type of livestock on the farm and the associated slurry or manure production. Water addition, through the use of wash water, leaking drinkers or rainwater collected on yards draining towards the store, will often result in a doubling of slurry volume following dilution. The addition of litter used for bedding, also needs to be considered, particularly in solid manure systems (Smith *et al.,* 2000b). In view of the potential for serious pollution, as a result of catastrophic failure or mismanagement of storage, it is clearly of crucial importance that storage requirements are adequately planned and that the stores themselves are well designed and managed.

Detailed costings are available for the full range of manure storage options and ancillary equipment, including silage clamps, silage effluent tanks, slurry stores and covers, reception pits, farmyard manure stores, concrete yards, irrigation systems and rainwater goods (Thompson, 2002). Current costs, based on a 1000m^3 slurry store, are approximately £30-34.m^{-3} for above-ground tanks, £22-24.m^{-3} for a weeping-wall store with effluent tank + irrigation system, £27-30.m^{-3} for a lined or concrete-based lagoon and £12-15.m^{-3} for an unlined lagoon.

It is clear that the high costs of storage can never be justified on the basis of the improved N conservation and the resultant potential for increased savings on fertiliser costs. However, farmers continue to have a poor perception of the value of manures and statistics on fertiliser use show little evidence of significant allowances being made for the nutrients supplied by manures. It is possible, therefore, that improved storage facilities and better manure management will release considerable economic benefit to the farmer, as yet largely unrealised, together with the environmental benefits. Additional benefits arising from well designed storage include system efficiency (in terms of spreading operations), convenience and protection of soil structure and physical fertility. Furthermore, an element of 'treatment' may be apparent in terms of BOD levels and in the decline of viable pathogens during the storage period, although this benefit is likely to be limited because of the continuous-fill operation of most slurry storage systems. An example is provided by current research on the soil treatment of dirty water, with the dirty water stored before treatment application. A reduction in BOD of 90%, from the initial level of ca 2500 mg.l^{-1} to 270 mg.l^{-1} was observed in the dirty water stored in tanks under ambient conditions, in only a 2-month period (Chadwick, personal communication).

Storage can thus act, both to reduce the BOD load at source and can reduce the risk of mobilisation and transport of pollutants, by precluding the presence of polluting nutrients and organic material from vulnerable situations, at times and under conditions of high risk.

4.3.3. Solids-liquid separation

This relatively simple process can offer advantages both in terms of the improved handling and management characteristics of the two products. There are two basic methods of solids liquid separation. One uses the difference in density between the solid particulate matter and the liquid (settlement or centrifuging) and the second uses the shape and size of the particles to cause separation (screening and filtration).

There can be several reasons and *advantages* for undertaking separation:

- improved infiltration of the liquid into the soil, for reduced odour and NH_3 emissions;
- reduction in herbage contamination with slurry solids and, hence, reduced risk of negative impact on silage quality or pathogen transfer to grazing animals;
- easier handling of liquids, facilitating improved accuracy of spreading;
- reduction of nutrient loading via slurry application (may be significant in cases of nutrient surplus);
- improved homogeneity of the liquid phase (with reduced sediment and generally no crusting);
- reduced storage volume for slurries;

- reduced energy requirement for mixing and pumping and reduced risk of blockages;
- reduced risk of blockages during subsequent operations;
- useful pre-treatment for biological processing.

Some *disadvantages* also have to be considered:

- storage, handling and spreading of two separate materials;
- necessary investment in machinery;
- farm labour and technical input requirement.

After solids are removed, they can be applied to land, dried, composted, or used elsewhere, e.g., in Japan composted solids have been used for bedding in dairy cubicle buildings.

Settlement
Solids with a density greater than that of water can be settled out by holding the effluent in a tank or allowing passage at low velocity. Fast-moving liquids pick up and transport solids; when velocity slows the solids settle. Settlement is most effective in dilute waste waters, e.g. flushing water, yard runoff (Miner and Smith, 1975). Settlement in these dilute effluents occurs fairly rapidly with most occurring within the first 10-20 minutes of retention.

Screening and filtering
Quicker separation can be achieved using a mechanical screening process. A wide range of equipment is available, usually involving sieves or screens in various configurations. These include run-down screen, vibrating screen, belt press, drum press, press screw/auger separator, sieve centrifuge, decanter centrifuge. Costs vary widely reflecting sophistication and performance. At the low end, are basic screening packages, e.g. sieves with pumps and mixing equipment, costing ca £15,000 and, at the high end are the centrifuges at >ca £60,000. In Italy, where slurry separation is amongst the commonest treatment systems applied at the farm level in the pig sector, investment costs are estimated as follows (Bonazzi, personal communication):

- rotary screen: €8,400
- vibrating screen: €8,400
- roller press: €8,400
- screw press: €8,400
- centrifuge - costs varying according to capacity and performance:
  - 2.5m^3 h^{-1}: €22,000
  - 6.0m^3 h^{-1}: €48,000
  - 12m^3 h^{-1}: €68,000
  - 25m^3 h^{-1}: €100,000
  - 35m^3 h^{-1}: €115,000

Despite the range of equipment available, relatively few have been taken up by farmers in the UK; recent estimates suggest that 8% of pig farms use some form of mechanical separation to assist in slurry management (Smith *et al.,* 2000b). Performance characteristics can vary substantially and depend on several factors, including:

- separator type
- sieve mesh size (also centrifugal force)
- slurry type
- additives (e.g. water; flocculent)
- solids content of the slurry

Performance is usually assessed in terms of slurry flow rate and relative output of solids and liquid, with separation % of solids and of the major nutrients, N, P and K. Data from a range of the more common separators are shown in Table 4.3. With suitable technology (i.e. correct equipment selection and set-up) a nutrient removal of up to 80% for P and 50% for N can be achieved. In this way, nutrients can be concentrated in the solid phase (only 10-20% of original mass) and the solids may be transported to regions that do not have a nutrient surplus, at reduced cost. The latter may be further reduced by composting the separated solids. It is then feasible that the separated liquid with relatively low N and P content may be irrigated to land at the production unit or subjected to further treatment, prior to land application or discharge.

Best nutrient separation results are provided by the decanter centrifuge, especially in terms of P reduction. The range in performance is the result of variable slurry influent and machine setting. To some extent this allows some adjustment in performance of the technique, depending upon objectives, e.g. maximum nutrient removal in the solids, or production of high dry matter solids which will compost easily and quickly. Separation can be expected to remove a significant proportion of the organic load from slurry, in terms of COD (with removal of the coarser solids) but might be expected to impact rather less on BOD and NH_4-N. Few data are available on these aspects of performance. However, Shutt *et al* (1975) reported the removal of 35% solids, 62% BOD and 69% COD from pig slurry, by a simple run-down screen, even with only 3% of the volume removed. Performance varied with the screen slot width (0.1cm better than 0.15cm) and slurry inflow rate. Operation of a vibrating screen with the same pig waste waters indicated rather lower removal efficiencies of BOD and COD (only ca 4% and 10-15%, respectively) than the run-down screen but with optimum application rate varying according to screen opening size.

Table 4.3 Separation efficiency and technical data for common separators (Burton & Turner, 2003)

	Belt press	Sieve drum	Screw press	Sieve centrifuge	Decanter centrifuge
Flow rate (m^3/h)	3.3	8-20	4-18	1.9-5.5	5-15
Separation efficiency %					
Dry matter	56	20-62	20-65	13-52	54-68
N	32	10-25	5-28	6-30	20-40
P	29	10-26	7-33	6-24	52-78
K	27	17	5-18	6-36	5-20
Volume reduction %	29	10-25	5-25	7-26	13-29
Specific energy (kWh/m^3)	0.7	1	0.5-2.0	2.2-6.7	2.0-5.3

4.3.4. Manure drying

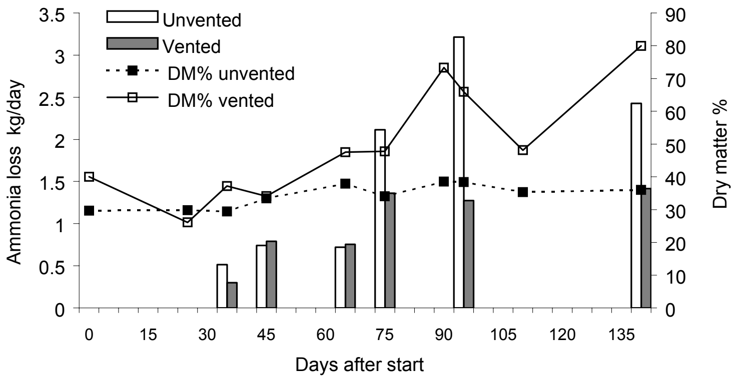
The process offers a number of potential benefits, including a reduction in mass and volume (hence easier and cheaper transport), manure stabilisation, reduction in emissions (possibly ammonia and odour) and a degree of sterilisation. On the other hand any process involving heat is likely to imply an increase in running costs as well as the necessary capital costs. Because of the potential cost implications, the process is more attractive for manures of high dry matter content (e.g. poultry manures) due to the smaller water volumes to be removed and the higher yields of dry product.

There has been particular interest in the potential for drying of poultry manures, an example of which includes a study on low-cost drying/stabilisation of poultry layer manure within deep-pit houses (Smith *et al.,* 2001b). Impacts of drying on the N metabolism of the manures are of major relevance to environmental emissions. The end product of most of the metabolised N in birds is uric acid ($C_5H_4N_3O_4$), rather than the urea ($CO(NH_2)_2$) produced in mammals. Uric acid is relatively insoluble and it can be excreted as a thick paste, at the expense of less water than is involved in urea excretion. Once uric acid is voided in droppings, it is potentially easily converted to NH_4-N by micro-organisms. Uric acid degradation will occur via several stages and the activity of both aerobic and anaerobic, uricolytic bacteria and some other micro-organisms, before the conversion of glycolate and urea to NH_3 and CO_2. Moisture content, pH and temperature have been identified as important factors affecting the degradation of N-containing compounds into NH_3. Increasing water content, in particular, leads to an increase in the microbial degradation of these components (Groet Koerkamp and Elzing, 1996).

Ventilated drying of layer manure in battery cage systems, using air-supply tubes over the manure cleaning belts, has been shown to be effective in reducing NH_3 emission as manure moisture content fell, with a sharp decrease in emission evident at dry matter contents above 60% (Groet Koerkamp *et al.,* 1995). Composting of mixtures of manure and litter will also reduce the moisture content of the mixture very effectively. However, composting is associated with increasing microbiological activity, usually with increasing temperature (up to 60-70 °C), which will encourage a substantial loss of NH_3 (Sommer *et al.,* 1998). A pilot-system design in a conventional, 10000 bird commercial deep pit house in Staffordshire, showed the potential for drying manure at relatively low temperatures and with significantly reduced NH_3 losses (Smith *et al.,* 2001b).

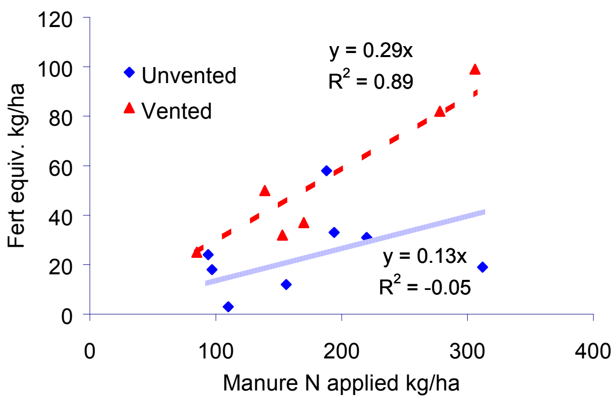
Results showed that a manure product of almost 80% dry matter could be achieved (compared with around 40% dry matter for untreated material). Also, that NH_3 losses via air exhausted from the pit could be reduced by up to 50%, once effective manure drying has been achieved (Figure 4.5). The initially disappointing results coincided with a period of low ambient temperatures and wet weather when, no doubt, the air drawn through the stored manure by the fan was of high relative humidity (RH), with little capacity for water absorption and, therefore, poor manure drying capability.

Figure 4.5 Effect of air drying on manure dry matter content (lines) and ammonia loss (bars); experiments on a commercial deep pit house, Staffs. (Smith *et al*., 2001b)



The reduced manure moisture content, lower temperatures and reduced pH (due to reduced NH_4-N content), factors known to contribute to reducing the rate of degradation of uric acid, explain the reduction in ammonia emissions associated with the drying treatment. The treated manure appeared to be "N-stabilised", with a consistently lower NH_4-N content and increased uric acid-N content, compared with untreated layer manure. This "stabilised" manure N has been shown by the results of field experiments, to be utilised consistently more efficiently than untreated layer manure N (Figure 4.6) and, it is likely that NH_3 emissions following land application of this material will be significantly reduced. Preliminary estimates of treatment costs suggested that these should be contained within ca £3.60 t^{-1}, or 14p $bird^{-1}$, based on the use of cheaper rate night time electricity.

Figure 4.6 Relationship between rate of manure N applied and fertiliser N equivalent measured in field experiments (Smith *et al.,* 2001b)



Groet Koerkamp (1994) concluded that forced drying of manure and litter provides real opportunity for reduction of NH_3 emission in the housing system. Control of air temperature, relative humidity and velocity enhance the removal of water during the drying process. It seems clear that reduction of NH_3 emission can be achieved by changing from deep-pit houses to battery systems with manure belts or scrapers and positive experience with fan-assisted manure drying on commercial units has recently been noted.

In this way, manure composting can be avoided and regular removal of manure to storage (external to laying accommodation) achieved. This research has shown how the recommendations of Groet Koerkamp can be applied to the deep-pit housing system and has demonstrated the added benefit of drying on the efficiency of manure N following land application – a potential "win-win" scenario for both the producer and the environment.

4.3.5. Anaerobic digestion

There is a substantial scientific literature on the development of and research into anaerobic digestion. Detailed review material is also available from a number of sources (Monnet, 2003; Svoboda, 2003; Burton and Turner, 2003) and thus only an outline is included within the current report. Anaerobic digestion is achieved by allowing micro-organisms to break down complex organic substances, in the absence of oxygen in a heated, enclosed digester vessel, at temperatures between the extremes of 25 and 70^0 C. Anaerobic digestion is, most easily and commonly, carried out on pumpable slurries, although more recently, high solids content (20-40% dry matter range) plug-flow reactors have been developed (Monnet, 2003). For slurries, although the optimum dry matter content is 6-8%, it is likely that the majority of cattle and pig slurries could be successfully digested, provided that excess bedding was excluded. One of the products of the process is biogas, a mixture of methane (60-70%) and carbon dioxide (30-40%).

The process can be either *mesophilic* (25-45^0C) or *thermophilic* (55-70^0C): although the latter process gives higher gas yields, equipment is more costly to install and is normally used only in large, centralised digesters. All digesters that are in commercial use in the UK operate on a continuous process, with a nominal retention time of 12-20 days: the lower figure for pig slurries, the higher for cattle slurries. (R J Nicholson, personal communication).

Typical residence time and temperature adopted in a farm scale mesophilic digester would be 15 days retention at 35^0 C. In a thermophilic process, typical time and temperature for farm slurries would be a minimum of 10 days at 55^0C*.* Some centralised anaerobic digestion (CAD) plants in Denmark have an additional 70^0C pasteurisation process built in, which adds significantly to capital costs. Considerable reduction of odour has been demonstrated (Pain *et al*., 1987) and significant reduction in the pollution potential of slurries as assessed by BOD_5 and COD (Table 4.4) (Hobson and Robertson, 1977).

In the results of Hobson and Robertson (1977), the quantity of total N in the waste was not changed, except for a small proportion of ammonia being transferred to the biogas. It appeared also that some organic N was reduced to ammonium-N, thus increasing the NH_4-N to a relatively high value (4-6 g l^{-1} NH_4-N), particularly in digested poultry wastes (Dohanyos *et al*., 2000). Phosphorus was also found to be partially released into the liquid phase, by digestion. Overall, therefore, anaerobic digestion decreases the C:N ratio and increases the concentration of immediately accessible plant nutrients. However, it is clear that the digestion process does not significantly reduce the volume of the slurry, nor its nutrient content.

Table 4.4 % reduction of BOD_5, COD, total solids (TS) and volatile fatty acids (VFAs) in slurries as a result of mesophilic anaerobic digestion.

Parameter	Pig	Poultry
BOD_5	75	80
COD	50	50
TS	40	60
VFA	73	80

Anaerobic digestion has been shown, also, to have a beneficial pathogen reducing effect (PRE) on effluents. In mesophilic systems, the PRE is modest and corresponds to a $\log_{10}$- reduction of 1-2 units. In contrast, thermophilic plants have been shown capable of achieving 'adequate' PRE of a $\log_{10}$- reduction of 4 units (Bendixen, 1999). Disinfection of road tankers using 0.2% NaOH solution is recommended in Danish CAD plants, to prevent cross contamination from undigested to digested livestock slurries (Bendixen, 1999).

Costs of the process and likely uptake/applicability. Whilst anaerobic digestion is 'proven technology' which has been available for over twenty years, uptake of the process has been minimal and restricted to enthusiastic farmers or those sites with specific factors, such as the need for odour control or a direct use for the biogas produced, which favour the process.

A study carried out in 1993 indicated that there were then only 43 digesters in the UK of which 23 were definitely operational at the time (R J Nicholson, personal communication). Since that date, a limited number of additional digesters have been installed, but others have gone out of use, including a large digester at Hanford Farms, Dorset. The latter was supplying electricity into the National Grid under a NFFO agreement. After approximately 15 years use, the digester vessel failed through corrosion. It appears likely that there are currently rather less than 30 plants operational on individual farms in the UK.

The main reason for the lack of uptake is thought to be the high costs of installation. Capital costs were estimated recently, in the order of £750 m^{-3} of digester capacity, which would equate to an expenditure of at least £60,000 to service a 100 cow herd (R Nicholson, personal communication). In Italy, the investment costs of a simplified biogas digestion plant consisting of a storage tank covered by a flexible sheet, with electrical power generation (60 kW) are estimated at €170,000, for a pig fattening unit with 350-400 tonne LW (up to ca 4000 places). Anaerobic digestion, with combined thermal and electrical power generation, are uncommon in Italy; costs of the latter can be estimated at about €300-500 m^{-3} reactor, with an additional €800-1000/kW capacity, electrical power generation (Bonazzi, personal communication). On the majority of holdings it is difficult to utilise all the gas produced, particularly in summer, when gas yields are highest. Payback periods are, therefore inevitably, very long.

Economies of scale favour large digesters. Under the EU 'ALTENER' programme, feasibility studies have been carried out on several UK centralised digesters, each aiming to serve a number of farms. A Danish-built plant at Cannington in Somerset is designed for a throughput of 200 tonnes/day of livestock slurries and other organic wastes and operates at mesophilic temperatures, plus pasteurisation. Capital cost is understood to be in the region of £4 million. Two companies, Holsworthy Biogas Ltd and German installation contractors Farmatic Biotech Energy built the UK's first centralised anaerobic digestion (CAD) plant in Devon with design throughput of 146,000 tonnes/year of cattle, pig and poultry manure together with organic waste from local food processors. Here waste is firstly mixed and pasteurised by heating to 70ºC within an hour. The mixture, cooled by a series of heat exchangers, is then pumped to one of two 4000m^3 reactors where it is digested for an average duration of 20 days. Treated waste is stored and redistributed back to farmers as a fertiliser. Following desulphurisation, which removes hydrogen sulphide (H_2S), the biogas generated by digestion is used to produce electricity and heat. Silsoe Research Institute are undertaking an evaluation of the process and plant performance (Assessing the environmental impact of centralised anaerobic digestion, Defra project CC0240) involving an environmental Life Cycle Assessment (LCA) of the CAD and compare technology, cost effectiveness and environmental impact with other manure management strategies. The Holsworthy plant received £3.85m grant from the EU Objective 5(b) programme and total project cost was estimated at £7.7m (Finck, 2002). Economics of such plants will depend on payment of 'gate fees' on non-agricultural wastes, which will form up to 25% of plant throughput. Large CAD plants are seen by waste disposal contractors as an avenue for disposal of liquid organic wastes, which they are discouraged from disposing of to landfill under the EU Landfill Directive. However, this approach presents considerable logistical problems of slurry transport to the central plant and transport of digested slurry back to farms for spreading to land. Important aspects are transport and system hygiene and planning approval. The performance of the Holsworthy plant, although technically successful, has been disappointing and in 2003 resulted in the plant being sold to a UK group involving the supplying farmers.

4.3.6. Aerobic treatment

Aerobic treatment of slurry is normally carried out only for odour control purposes and this is achieved via the microbial breakdown of the many compounds (organic and inorganic) that contribute to manure odour. This results in the stabilisation of organic compounds and, hence, the reduction of COD and BOD. Reduction of pathogens and improved physical and chemical characteristics are other significant benefits. Aerobic treatment is generally only suitable for separated slurry or dilute effluents (<3% dry matter) containing no bedding (Anon 1998b). Unseparated pig slurry can be aerated, whereas cattle slurry may require both dilution and mechanical separation for the process to be trouble-free and effective. A number of approaches are used to achieve aeration, either in-situ in the slurry store, or in a purpose-designed aeration vessel. These range from blowing compressed air through porous diffusers with very small outlets, or by entraining air in a fast moving stream of liquid in submerged nozzles, or floating devices with discs or rotating impellers (Cumby, 1987a). Motive power for these devices is provided by electric motors. Temperatures of the aerated slurry will rise by 5-25^{0}C depending on the slurry analysis, degree of aeration, tank insulation and ambient temperature. The process can create foam and its control can be a problem (Cumby, 1987b). Continuous flow systems can reduce slurry odours with a retention time of 1-2 days, provided that a reasonably constant and well-mixed flow of slurry is maintained.

Livestock slurries can be aerated for a range of times, dissolved oxygen concentrations and temperatures. Also, the aeration can be run as a batch or a continuous process. All of these parameters affect the characteristics of the treated slurries. The most efficient is a continuous culture process, and therefore most research has been devoted to it. As a continuous process, aeration will generate heat and can be performed at mesophilic temperatures (25 to 45ºC) and thermophilic temperatures (50 and >50ºC) (Evans *et al*., 1983). Laboratory experiments provided data allowing the generation of mathematical equations describing the characteristics of treated pig slurry at those temperatures. Thus:

$BOD_5 = 1.568/R + 0.152BOD_f$

Where:
R is the mean treatment time (days), and
BOD_f is BOD of the fresh slurry (g/l)

Thus, pig slurry of 10%dry matter and BOD, typically of 35g l^{-1}, after 5 days of mesophilic aeration, would have a BOD of 5.6g l^{-1}, or ca 16% of the original BOD. Such continuous aerobic treatment is known, also, to result in strongly offensive pig slurries becoming inoffensive (by odour panel assessments) within 2-3 days at mesophilic treatment temperatures (Evans *et al*., 1983).

As well as the oxidation of carbonaceous and other matter in slurries, nitrification of ammoniacal N is also an important phase of aerobic activity, which has been described as a two-step process (Sharma and Ahlert, 1977):

$NH_4^+ + 1.5O_2 \rightarrow 2H^+ + H_2O + NO_2^- + 58$ to 84 kcal (heat)
$NO_2 + 0.5O_2 \rightarrow NO_3 + 15.4$ to 20.9 kcal (heat)

Several studies have been made into the effects of slurry storage on pathogen levels. A 90% reduction of Salmonella occurred within 2-4 weeks in anaerobically stored cattle slurry and within 2 days in aerated slurry (Jones and Matthews, 1975). Aeration also increased reduction of Campylobacter in dairy slurry (Stanley *et al*., 1998). Aeration of farm-scale slurry tanks stored under winter ambient conditions increased the temperatures to between 19^0C and 40^0C and reduced Salmonella levels by over 99% after 2-5 weeks for both cattle slurries contaminated with *S. infantis* and pig slurry contaminated with *S. typhimurium.* In this study similar effects were found for Yersinia, Listeria, faecal coliforms, enterococci and coliphages. (Heinonen-Tanski, *et al*. 1998).

Costs of the process and likely applicability. Some detailed costings are presented by Svoboda, 2003. The purchase of a simple aerator represents a modest investment in Italy (Bonazzi, personal communication):

- floating mixer-aerator : €3000
- submerged mixer-aerator: €3600

However, aerobic slurry treatment systems are expensive to install and require a high energy input in the form of electricity. Williams *et al* (1989) measured energy input required to stabilise pig slurry in an odour-free state. Even with efficient transfer of oxygen, there was a minimum requirement of 0.11kWh pig place^{-1} day^{-1}, which at recent (1999) cost of say 7p kWh^{-1} equates to a minimum running cost of £3.65 pig place^{-1} year^{-1} for effective odour control. This would represent a cost of £3-4.m^{-3} for pig slurry and £3-4.m^{-3} for cattle slurry, with a 5-day treatment regime (R Nicholson, personal communication). Adding interest and depreciation on capital costs, plus maintenance charges, is likely to double this cost to a minimum of £7-8 pig place^{-1}year^{-1}. The need for adding mechanical separation equipment could add to these costs. In Italy, sequencing batch reactor (SBR) plant for the treatment of the liquid fraction, after solids separation and with specification to meet the requirements of final treatment in municipal treatment plants, require considerable investment. This is estimated at ca €100,000, for 800-1000 tonne LW fattening pigs (slurry production at ca 150m^3/day) (Bonazzi, personal communication). Costs of continuous aerobic treatment plant with similar capacity to the SBR are estimated at ca €120,000. In a similar way to anaerobic digestion, therefore, the majority of the livestock industry has not and is unlikely to invest in such aeration systems.

It is estimated that up to 10% of pig slurry in the UK is aerobically treated, but that few installations exist to treat cattle slurry. Design parameters for aeration systems vary enormously and are very often a case of 'stick this aerator in the tank and see how it goes'. Systems are often fitted with timers to allow a degree of control over running time and cost.

A number of agitation systems using relatively small amounts of air to mix slurry at intervals have been installed, but are unlikely to achieve significant oxygenation. There therefore is no guarantee that existing systems would always achieve conditions conducive to significant reduction of BOD or odour or pathogen control.

4.3.7. Solids composting

The composting of solid manures and organic wastes has become increasingly popular. This results, possibly from the claimed environmental benefits, the commercial interest in composted material and the reduction in landfill charges that may be averted, as a result of diverting wastes to an alternative route. Composting of solids may sometimes involve the use of slurries, as a source of nitrogen. Also, composted manures will pose a much reduced risk of pollutant run-off during storage or following land application, as a result of metabolism and stabilisation of organic compounds that otherwise may contribute to such pollution.

The application of composting processes may result in the following benefits:

- Volume and mass reduction of manures due to decomposition of organic matter, through the emission of CO_2 and water loss;
- Stabilisation of manures, resulting in reduced emissions during storage and following land application;
- Inactivation of weed seeds and some pathogens;
- Changed nutrient availability (this can be both an advantage or disadvantage);
- Opportunity to develop alternative specialist applications, e.g. recycling of composted material as livestock bedding, use as horticultural growing medium/soil amendment;
- Scope to transport/export surplus nutrients to regions deficient in nutrients;
- Associated with a positive public image for wastes recycling and environment protection.

There are three main types of composting systems:

1. Windrow
2. Static pile with forced ventilation
3. In-vessel

Control over the composting process increases from windrow to static pile and in-vessel composting, as does the capital cost. The labour cost decreases in the same succession and the overall running cost mainly depends on the costs of labour and energy.

Windrow composting. The feed stock is piled in long rows (windrows) and turned at intervals using mobile equipment like tractors with front loaders or compost-turners, machines specially designed for compost turning. The most common method, the conventional windrow, is aerated through natural ventilation (convection and diffusion), and also during turning, which is also required for more homogenous composting. This process requires an extensive area of ground which can be compacted soil, but more ideally a concrete base with the facility for containing any leachate. In regions with high rainfall, leachate production can be reduced and improved control of composting achieved by roofing the composting area.

Static pile composting. This process uses an active aeration system. Perforated pipes are laid on the floor or in the floor channels and are covered with porous material like straw, wood chips etc., which aids efficient distribution of air. The feed stock is then piled on the base and covered with a layer of matured compost to provide thermal insulation and partial odour removal.

Aeration, controlled by temperature feedback, is used to sustain the pile in an aerobic state, to maintain the temperature of the pile and to control the moisture content of the pile. The latter helps mainly in the final stage of composting, when the increased aeration rate contributes to compost drying.

In-vessel composting. This process is used to ensure homogeneous composting, inactivation of pathogens and odour reduction. In-vessel composting includes temperature control and is usually a multistage process. Pre-composting or full composting is achieved in the first stage in a bioreactor, and the final composting and maturing in windrows. The most common types of reactors are horizontal and vertical plug-flow and, also, an agitated bin reactor. Some systems incorporate computer control of temperature and oxygen levels. The quality of exhaust gases is often improved by passing them through a biological filter for odour and ammonia removal. This type of composting, being well controlled and thoroughly mixed, is faster than the previous systems, but the more complicated control and processing mechanisms are expensive and require costly maintenance.

While the moisture content decreases from about 70% to less than 30% and the organic content from about 75% to 50%, the concentration of phosphorus and metals increases in relation to dry matter content. By oxidising the biodegradable carbonaceous compounds to CO_2 the compost is biologically stabilised, i.e. when stored without access to air and rewetted, it does not generate any odorous compounds and its biological activity is minimal. This also means that the potential BOD emissions, e.g. in leachate from stored material is greatly reduced. Odour is produced mostly at the beginning of composting, when odoriferous compounds already contained in the feedstock are released in the exhaust gases by the increased temperature and forced aeration or turning. To minimise odour emissions, the windrows are covered with mature composted material or the air sucked from static piles is filtered through a biological filter.

Costs and applicability. The windrow composting method requires the least capital investment but has the highest labour input. An assessment of the costs of storage and windrow composting, taking account of depreciation, interest on capital, repairs, tractors, labour and electricity costs, is summarised in Table 4.5 (Nicholson, 2001).

Table 4.5 Typical net costs* per tonne of solid manure storage or composting systems (costs rounded to nearest £0.10). (After Nicholson, 2001 – Defra scientific report WA0656)

	Measure	Pigs/Poultry
		(£/tonne)
Storage	Storage earth-based	£1.30
	Storage concrete base-one store	£3.10
	Storage concrete base - two stores	£4.30
Treatment	Composting earth-based	£2.10
	Composting concrete base-one store	£4.30
	Composting concrete base - two stores	£5.80

* Costs calculated as those incurred compared to spreading direct to land with NO storage or treatment. Workrates used are in line with those used in the SPREADS DSS. Capital costs amortised over 15 years @ 10% interest (= £131 per £1,000 per annum). Maintenance and repairs taken as a % of initial capital cost, ranging from 3% for storage to 7.5% for slurry treatment by aeration. Where possible, costs have been based on Nix (2001). Figures used are tractor @ £11 hour^{-1}, tractor and trailer @ £13 hour^{-1}, tractor and loader @ £13 hour^{-1} and labour at £5.50 hour^{-1}.
Solid manure storage - 90 day store = 250 tonnes capacity. Additional tractor and labour hours to fill store, rather than spread direct to field = 15 hours per 250 tonnes.
Composting - Assumed that an additional 20% capacity is required in the store, to give space for turning. Additional (10 hours) tractor loader and labour hours per 250 tonnes for turning.

The cost of in-vessel composting would be prohibitive for farmers if, for example, a system which provides continuous composting with internal mixing and biofiltration of exhaust gases, were to be used. The indicative cost of plant would be around £0.75 million and depending on the waste stream, treatment of one tonne of manure could be in excess of £50. However there is potential for poultry manure to be used as an amendment in such systems to assist with the composting of the main waste streams. Since the treatment of slurry would require the addition of bulking material, like straw, wood chips etc., the advantage of reduced waste weight and volume due to composting would be compromised. For livestock slurries, the necessary addition of dry matter to reach the necessary solid concentration (25-35 %) can be so high that composting may become impractical. For example, starting with one tonne of livestock slurry of 5% dry matter content, the feedstock requires an addition of 0.3 tonnes of dry bulking material in order to obtain a mixture with 25 % dry matter (Piccinini *et al*., 1995). Also, by converting the slurry management to straw-based systems between 5 and 15% of livestock places would be lost (Nicholson *et al*., 2002). In Italy, composting of poultry manure is one of the treatment options considered as potentially viable, though only based on a centralised plant within a cooperative organisation; farm-scale operation is not considered viable (Bonazzi, personal communication). There are discussions concerning the feasibility for three or four centralised plants of 30,000 – 100,000 tonnes capacity each, with apparently two of these considered to have strong prospects of being commissioned. Estimated costs are as follows:

- 30,000 t annum^{-1} litter processing in roofed windrows: €3.5million investment costs with €50-55 t^{-1} litter processed running costs;
- 50,000 t annum^{-1} litter processing as above: €5.53million investment costs;
- 100,000 t annum^{-1} litter processing as above: €9.9million investment costs;

4.3.8. Use of treatment additives

Numerous additives have been investigated over the last three decades, including a large number of commercial products which are intended to help prevent or to alleviate the main problems associated with the manures arising from intensive livestock production:

1. The volatilisation of ammonia (NH_3);
2. The release of offensive odours;
3. Handling problems due to the formation of crusts and sediments during storage;
4. The pollution of surface waters.

The most common additives include; bacterial/enzymic preparations; plant extracts; chemicals including acids, oxidising agents, disinfectants, urease inhibitors, masking agents or products with physical properties such as adsorbents. However, the effectiveness of these additives, particularly the commercially available products, has been the subject of much debate (Pain *et al*, 1987; Ritter, 1989). The role of manure additives in minimising the impact of accidental discharges of slurry or dirty water is yet to be specifically investigated. There would however, appear to be potential for additives to reduce both the BOD_5 and nutrient loading of livestock slurry. Reductions in BOD_5 loading would appear feasible through enhancing the degradation rate of organic matter. Williams (1983) found that the VFA fraction of slurry accounted for up to 70% of its BOD_5; additives that degrade the VFA fraction may well, therefore, lower BOD_5. Commercial digestive additives claim to lower BOD_5 but no experimental evidence of this effect can be found. The mechanism by which the activity of these products might be achieved is not specified, so it can only be assumed that they may enhance the degradation of VFA fraction in the slurries. McCrory & Hobbs (2001) postulated three alternative mechanisms for these effects. Firstly, the additives may add micro-organisms that degrade the organic compounds found in livestock slurries more readily than the natural population. Secondly, they may add enzymes which catalyse the degradation of more recalcitrant organic compounds in livestock slurries, rendering them easier to degrade by the natural or added micro-organisms. Thirdly, they may add an additional carbon source. It would be assumed that the chosen carbon source would have a high C: N ratio and be readily available to micro-organisms.

The potential impacts of manure additives on nutrients, in particular N and P, have similarly received scant attention. A number of additives may have some effect on NH_4-N levels in manures, via microbial oxidation, degradation of organic N or, conversely, incorporation into microbial biomass. Adsorbent materials, such as zeolites, can adsorb and conserve N in the slurry. Other additives can impact on slurry pH and so affect the balance of N flux reactions, increasing or decreasing NH_3 emissions from the stored effluent. Phosphorus removal has largely not been investigated in the normal context of manure additives. However, there has been considerable progress under "manure processing" where there appears to be significant potential for P recovery, either via biological treatment or via two crystallisation pathways to produce magnesium ammonium phosphate (struvite) or calcium phosphate (apatite) (Greaves *et al.,* 1999).

A series of laboratory experiments were undertaken on pig and cattle slurries, with a range of commercial additives and some single component agents (Hobbs, 2000). Limited effectiveness of most commercial slurry and solid manure additives was clearly demonstrated. Most products claimed microbial activity and often had low counts of viable organisms coupled with poor growth characteristics in slurry, largely due to limited availability of appropriate substrate.

Costs and applicability. Compared to other options, the use of manure additives can appear attractive, as generally there is no need for capital expenditure. The initial cost, quantity required, frequency of application, and hazard potentials of an additive are the most important considerations. As slurry will be continually accumulating in a store, it is likely that all additives will need to be added at some frequency. Microbiological additives though, may benefit from continuous accumulation of slurry. To effectively immobilise N, micro-organisms need to maintain a high population. Frequent application of fresh slurry may provide the readily available organic matter needed for maintenance. The need for frequent addition of additives to slurry could be eliminated if additives are placed in the feed of livestock. Although several examples were presented in the literature, little work has been done in this area, and further research is required. There appears also to be the need to assess the influence of some other additives with regard to possible impact on BOD capacity. It would seem likely that additives that inhibit microbial degradation may well also inhibit any 'natural' reduction in effluent BOD, as a 'side-effect' of their main activity.

In the light of the very limited supporting research data indicating benefit, additives are unlikely to find wide/popular applicability. It still seems likely that much of the commercial uptake of these products is on a "first encounter" basis, with little repeat business.

4.3.9. Manure processing (including phosphate recovery)

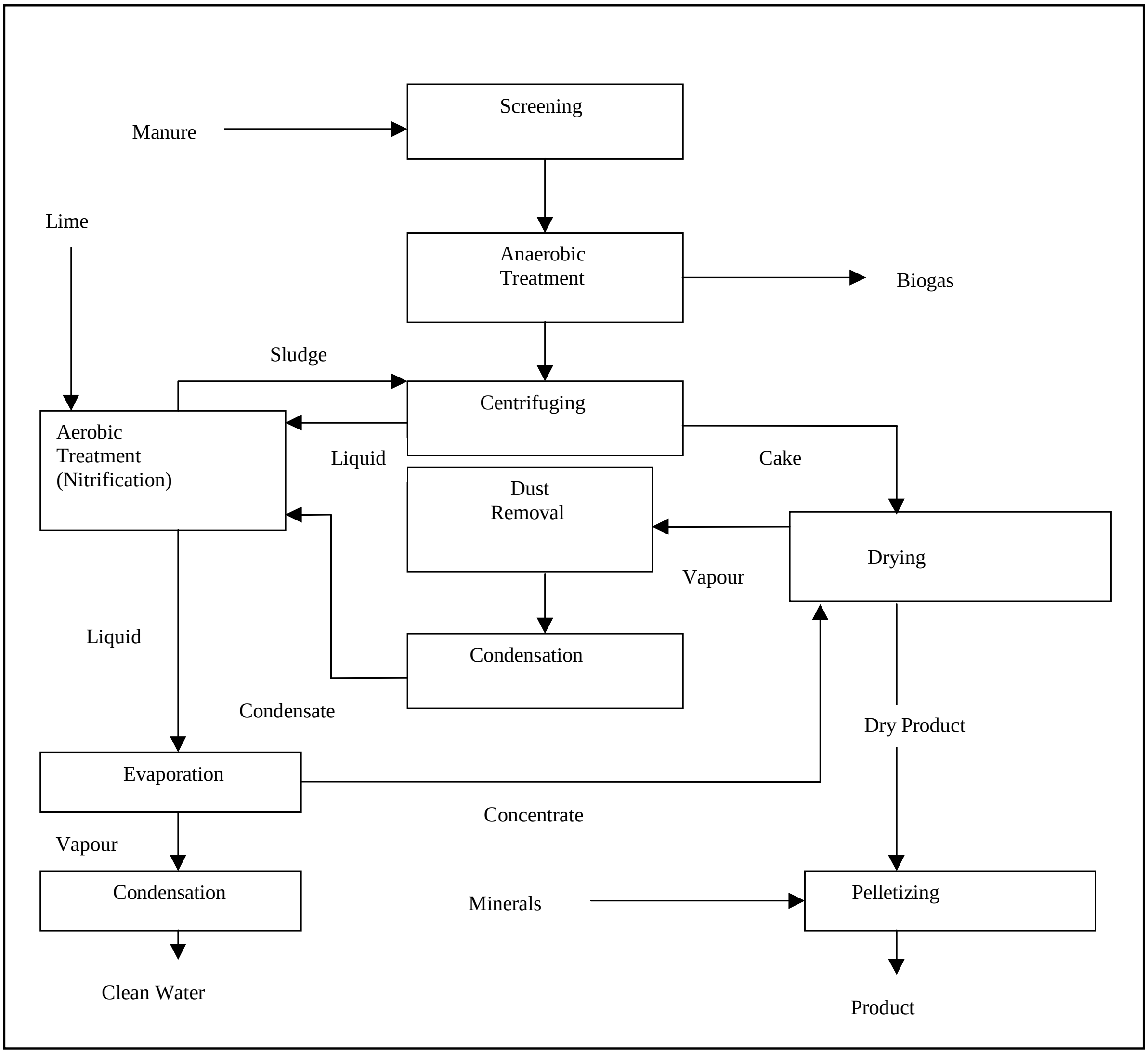
In addition to the movement of manures from areas of surplus to areas of low manure availability and attempts to limit livestock numbers, large scale manure processing might be a useful strategy for abatement of environmental problems associated with livestock manure surpluses. It was, for some time, regarded as the best solution for the surplus of pig manure in the Netherlands (Ten Have, 1993). Processing of liquid manures, whether on a single farm, or regional scale, comprises a series of basic treatment steps, logically arranged. The detail of the steps and optimal arrangement depend on the slurry composition, on local circumstances and on the required products and product quality. The basic steps considered feasible, at the present time, comprise 8 groups of options that may be combined or used as alternatives (Table 4.6).

Table 4.6 Basic treatment steps in animal slurry processing (after Rulkens *et al*., 1998)

1) Separation of colloidal and suspended particles: • Filtration (in combination with coagulation/flocculation) • Centrifuging (in combination with coagulation/flocculation) • Sedimentation • Separate collection of urine and faeces in pig houses.	5) Removal or concentration of minerals: • Evaporation (production of concentrate and condensate) • Reverse osmosis (production of concentrate and permeate) • Freeze concentration (selective removal of water) • Catalytic incineration
2) Removal, concentration or conversion of organic compounds (soluble and insoluble): • Mechanical separation of colloidal and suspended particles (filtration or centrifuging resulting in a sludge (cake) and a liquid phase) • Anaerobic treatment • Aerobic treatment • Wet Oxidation (subcritical or supercritical) • Hydrothermolysis (supercritical)	6) Treatment of the manure cake and concentrate from evaporator or reverse osmosis process: • Drying (production of a dry cake and a gas phase containing water and volatile compounds) • Incineration of the wet or dry cake aimed at energy production • Pyrolysis • Gasification
3) Removal, concentration or conversion or immobilisation of N compounds (including ammonia): • Stripping and absorption in mineral acid • Nitrification (immobilisation) • Denitrification • Acidification with mineral acids (immobilisation) • Ion exchange • Precipitation as ammonium magnesium phosphate • Membrane separation	7) Treatment of exhaust gases from a drying process: • Dust removal • Condensation • Bioscrubbing • Biofiltration • Incineration
4) Removal of phosphorus: • Filtration/separation of colloidal and suspended particles • Precipitation (soluble compounds) • Biological phosphate removal	8) (Micro)biological conversion of nitrogen : • Production of fungi • Production of algae • Production of amino acids • Production of bacteria • Production of yeast • Production of duckweed

The Promest, central processing system developed in the Netherlands is shown in outline in Figure 4.8 (Rulkens and Ten Have, 1994). In the operational plant, raw pig slurry was digested anaerobically and the digested slurry separated into solid and liquid fractions. Aeration of the liquid fraction, under pH-controlled conditions promoted nitrification. Effluent from the aeration process evaporated, generating clean water and a concentrate. The concentrate, dried with the slurry solids and sludge from the aeration tank, was used to generate the organic fertiliser product (lower RH corner of Figure 4.7). Nitrification during the aeration stage enriched the N fertiliser value of the product and other minerals were added according to product. The final product was dried at 120°C to ca. 90% dry matter content (range 81% - 96%) and finally pelletised.

Figure 4.7 Simplified process diagram of the Promest system (after Rulkens *et al*., 1998)



Details of composition of the processed pig slurries (Table 4.7) and, also, the results of "relative efficiency index" (REI) have been provided by van Erp and van Dijk (1992). Comparison of the analysis of the processed slurries (PPS) with the untreated slurries (APS) shows that losses of N occurred during the processing. Most of the mineral N in the final product was in the NO_3-N form.

In these studies about 34% of the organic C content was removed, as CH_4 and CO_2 during the processing. Only a small proportion of P (ca 8%) was in water soluble form but most (>90%) of the K is water soluble, indicating that almost all is readily available for crop uptake. Pot experiments on the availability of the PPS nutrients showed that the REI of the total N was marginally higher than the mineral N content, while that of the P was lower than that of the untreated slurries. It was concluded that the processing improved the fertiliser value of the slurry compared with that of untreated pig slurry.

Table 4.7 Composition of processed pig slurries (PPS) in % of dry matter and comparison with typical composition of pig slurries in the Netherlands (after van Erp & van Dijk, 1992)

Component	PPS[1]-(A)	PPS-(B)	PPS-(C)	PPS-(D)	PPS-(E)	APS[2]
Ash	38.7	38.1	37.1	34.5	38.1	33.8
Organic C	n.d.	n.d.	25.7	26.8	27.1	38.4
N_{total}	5.95	5.83	5.9	4.7	3.77	8.8
NH_4-N	0.21	0.18	0.2	0.55	0.39	3.8
NO_3-N	3.58	3.36	3.43	3.21	2.07	n.d.
P_{total}	2.10	2.11	2.10	2.21	2.96	2.3
K_{total}	7.26	6.63	6.73	6.37	4.43	7.5
Pellet diameter mm		3	6	4		

[1] PPS = Processed pig slurries
[2] Average pig slurry analysis – assumed DM content ca 7.4%.
n.d. – not determined

At one time up to 8 processing plants were at various stages of development (Ten Have, 1993), but despite the technical success of the Promest project and others, this research failed to generate applicable technology. It has been suggested that, in practice, very little has been achieved in the treatment of pig manure (Anon, 1998c) with the exception of manure separation techniques which are in occasional use. The report by the van Ruiten Adviesbureau B.V. (Anon, 1998c) concluded: “No major developments are expected in the field of manure processing. After the Promest debacle and the failure of other large-scale initiatives, the time for the centralised industrial processing of pig manure is over.”

In fact, the introduction of central pig slurry processing failed, mainly because of high costs and the lack of sound organisational and financial basis, as well as a well-organised network for the distribution and marketing of the products (Rulkens *et al.,* 1998). The anticipated effect of (regulatory) farm-scale measures on (the reduction of) manure volume and composition, also had a negative effect on the introduction of central processing. The cost of processing, at ca €25-30 t^{-1} was too high and could not compete with local arrangements for disposal on neighbouring farms (H Willers, Wageningen UR, NL, personal communication). The Promest system is no longer in operation.

In the Netherlands the sole surviving centralised processing plant is the Mestverwerking Gelderland Farmers Cooperative (MGFC) veal calf manure treatment plant at Putten, Gelderland. This remains successful because of the increased scale input possible as a result of many farmers operating with intensive production in the area. Phosphorus removal at this plant has been successful via precipitation of ammonium magnesium phosphate ($NH_4MgPO_4.6H_2O$; struvite) or potassium magnesium phosphate ($KMgPO_4.6H_2O$) (Greaves *et al,* 1999). The P content of the calf manure influent is reduced from ca 600 $mg.l^{-1}$, to a final effluent P content of < 30 $mg.l^{-1}$. The recovered struvite is added to the de-watered sludge from the biological treatment stage and returned to the farms by land spreading (in a much-reduced volume). Previously, P removal from the influent was achieved by the addition of lime, but this increased sludge volume by 30% and, hence, increased transport costs. More than 30% of the struvite precipitate consists of phosphate (PO_4, equivalent to 23% P_2O_5) and can readily be concentrated. It is anticipated that the nutrients in struvite will be readily available for crop uptake (Anon, 1998c).

In general, it seems that manure processing at source may prove to be the only viable option for this approach. Centralised treatment plants in high pig density areas of N. Italy failed due to the high polluting load from the treated effluent and the opposition of local residents (Bonazzi and Piccinini, 1998). Co-operative systems of pig slurry management are claimed to have greater chances of success; treatments are carried out on single farms, while the management of the systems is the responsibility of the co-operative. Treatments include solids separation, composting and, in some cases, purification of the liquid fraction. The costs of treatment, compost transport (removal from the area) and land spreading of the liquid within the area, are claimed to be sustainable. Performance data from the extended monitoring of a farm plant on a large pig unit in N Italy are shown in Table 4.8. The farm had capacity for 610 sows and average liveweight of 750 tonnes. The slurry treatment plant has been operating since 1991 and comprises solids/liquid separation with two centrifuges, one for raw slurry and one for surplus sludge, followed by anaerobic treatment with pre-denitrification, oxidation-nitrification, sedimentation and effluent discharge to the municipal sewer. Whilst co-operative based systems are regarded favourably in Italy, the costs are difficult to estimate because they are highly dependent upon regional considerations.

Table 4.8 Performance of the farm-scale treatment plant for pig slurry over a two year period (Piccinini and Bonazzi, 1996). (n= 23 samples)

	Influent		Effluent		Removal %	
Parameters	Mean	s.d.	Mean	s.d.	Mean	s.d.
TS ($g.kg^{-1}$)	20.71	7.2	-	-	-	-
TSS ($g.kg^{-1}$)	15.73	7.49	0.12	0.10	99	1
COD ($mg.l^{-1}$)	22089	8257	467	124	98	1
N_{total} ($mg.l^{-1}$)	1990	623	34	43	98	2
NH_4-N ($mg.l^{-1}$)	1420	419	15	32	99	2
NO_3-N ($mg.l^{-1}$)	-	-	48	33	-	-
P_{total} ($mg.l^{-1}$)	656	239	31	10	95	4
BOD_5 ($mg.l^{-1}$)	-	-	132	83	-	-

Similar high levels of performance have been demonstrated by treatment plant installed on a large pig unit (4,400 finishing place) in N Carolina (Vanotti, 2004) and at the Veterinary Science Faculty Farm, University of Murcia, Spain (Martinez-Almela *et al*., 2004). Two separation stages are included, with the efficiency of the second stage greatly increased by the injection of polymer compounds, to enhance solids flocculation (Figure 4.8b). Performance data indicate the removal of 97% TSS, 99% BOD, 99% N and 95% total P, with only marginal differences between the results with the plants in Spain and USA. Products are the treated effluent, which can be recycled as flushing water in the slurry channels or used for crop irrigation, and the separated solids.

Figure 4.8 Treatment plant for pig slurry at the Veterinary Science Faculty Farm, University of Murcia (RAMIRAN 2004, October 2004)

(a) Reactor tank for removal of slurry N

(b) Addition of polymer to enhance solids removal

In Flanders, one of the targets of the current Manure Bank was 50% processing of the manure production (Anon, 2001). This represents ca 30,000 t P_2O_5, whereas the actual achievement in 2003 was the processing of 7,200 t P_2O_5. With poultry manures, many companies are said to have adopted drying and partial composting, sometimes with further conditioning of the solids with other materials. Most of the processed manure is exported to France (71%) and the Netherlands (22%) (van Gijseghem, Vlaamse Landmaatschappij, personal communication).

4.3.10. Solids pelletising

Some more novel options, arising from or linked to manure processing, also need to be considered. In the US State of Delaware, the world's largest chicken manure pelletisation plant has processed about 60,000 tons of chicken manure since it opened in July, 2001 (DNREC), (Anon, 2004). The plant was designed as a solution for poultry farmers in the area who needed to remove waste from their facilities. Most had no option but to spread it on fields according to their Nutrient Management Plan, or store it in special leak-proof structures. A large farming company researched different methods of addressing the surplus manure, including incineration (an idea that was abandoned due to the cost and complexity of meeting emissions restrictions) or a composting facility (which proved to have too many logistical problems). The pelletisation plant, "Perdue Agr-Recycle", which handles manure from both Delaware and Maryland, was chosen because the waste could be transported easily before and after processing and it produced a marketable product. After an investment of $13 million from the company, and a grant from the State of Delaware, the plant was built to handle up to 95,000 tons of manure a year. Most pellets are sold directly to farms or other outlets (e.g. golf courses) in 1 tonne containers, but smaller pellets are sold via the retail trade, giving rise to products such as "Fertile GRO" and "Cockadoodle DOO" in the US. Such products have been available for many years in Europe and an example is "Rooster Booster" currently selling at £3.48 per 7 kg bucket through B&Q. Concerns about odour and emissions from the US plant seem to have been allayed by almost two years of operation with few complaints.

4.3.11. Combustion

In 1992, the 12.7MW power station at Eye, Suffolk became the world's first poultry litter fuelled generating plant. Since then further plants have been commissioned in Glanford, Scunthorpe, N Lincs (1993), Thetford, Norfolk (1999), Ely, Cambs (2000) and Fife, Scotland (2001). All except Ely are or have been used for burning poultry litter; the Ely plant being designed specifically for straw burning. The current net consumption of poultry litter amounts to ca 690,000 tonnes (Table 4.9), which represents over 30% of total UK production from litter based poultry and provides a major sink for the removal of poultry manure from agriculture. The Westfield plant in Fife consumes around 90% of litter produced in Scotland. The consequential reduction in nutrient loading (particularly of N and P) will have beneficial environmental impact in areas with high concentrations of poultry production. This also results in an estimated reduction in total emission of NH_3, of ca 2.7kt, or ca 7.5% of calculated emissions from the UK poultry sector for 2002 (Misselbrook *et al*., 2003).

Table 4.9 Capacity and fuel consumption of biomass fuelled power generation plants.

Site and location	Project cost	Commissioned	Capacity (MW)	Fuel sources	Annual fuel demand[1] (t)
Thetford, Norfolk	£65m	June, 1999	38.5	Poultry litter	**420,000**
Ely, Cambridgeshire	£60m	Dec, 2000	38	Cereal straw	200,000
Eye, Suffolk	£22m	July, 1992	12.7	Poultry litter, bedding, feathers	**160,000**
Glanford, N Lincs	£24m	Nov, 1993	13.5	Meat and bone meal (poultry litter)	89,000
Fife, Scotland	£22m	Jan, 2001	9.8	Poultry litter	**110,000**
Moerdijk, Netherlands[2]	Not known	-	30	Poultry litter, feathers	**358,000** **20,000**
Apeldoorn, Netherlands[3]	Not known	-	30 + 20	Poultry litter	Not known
			Total consumption of poultry litter (UK)		**690,000**

Note: [1] Fuel use figures from EPR website, 2004 and assumed to apply to 2003.
[2] DEPR NL, full planning permission and Environmental Authorisation agreed.
[3] Fibrowatt and Dutch Partner, Bio-one – CHP plant, 30MW electrical and 20MW heat.

Poultry litter is usually relatively dry (ca 60% dry matter content; Anon, 2000, ca 67% – 70% dry matter in this study) and, in this form, is readily combustible and is compatible in terms of its energy potential to another major preferred fuel source, straw (Table 4.10). Layer manure, because of its higher ash content, is marginally less suitable, but providing moisture content is reduced below the UK typical and ash content is controlled, would also appear to have potential for incineration. A potential constraint to achieving this may be the impact of Council Directive 99/74/EC on the welfare of laying hens. This Directive has created a degree of uncertainty as to the future of caged production systems in the UK. Cage systems offer the greatest potential for manure drying and are capable of producing dry layer manure of circa 60% - 70% dry matter, although free-range systems are also capable of producing dry manure. In view of the uncertainties facing the industry, it is expected that a greater number of producers may opt for free range or aviary systems rather than cage systems. Farm scale trials in Gloucestershire, in the early 1990s confirmed that broiler litter was a good source of renewable energy, with a net calorific value of 13.5 MJ kg^{-1} (Scott, 1999). The process is technically complicated and the capital

investment requirements, therefore high. The published project costs of the UK facilities (Table 4.9) range from £22m for Eye and Fife, to £65m for Thetford.
Running costs have been estimated at ca €1 tonne^{-1} dry solids in the feedstock (Burton and Turner, 2003), though must vary considerably according to the moisture content of the manure and transport costs.

Table 4.10 Composition and energy potential of biomass fuels (taken from Phyllis, 2004)

Source of biomass	DM %	Ash %	Calorific value MJ/kg	
			Dried	SAR[1]
Wheat straw	90.3	5.9	17.51	15.57
Broiler litter	60.3	17.5	15.77	8.54
Hen manure	66.0	25.3	13.38	8.00

[1] SAR = sample as received

The price paid by the power company for litter (details of which are confidential), as loaded on the farm, is dependant upon both the moisture content and ash content, the price per tonne increasing with decreasing moisture content above a threshold for acceptability of 50%. The price paid is also discounted on the basis of ash content, with full price paid (based on moisture content) on manure with <22% ash content, 0% paid on manure with >31% ash and pro-rata adjustment on a sliding scale in between. Thus it is difficult for conventional deep pit layer systems to produce manure that is acceptable for burning, either because of low dry matter content (typically ca 30-40%) or, ash content. The latter is elevated in layer manure because of the addition of lime to the ration to ensure good calcium nutrition and its impact on eggshell quality. Commercial egg producers indicate manure dry matter content of 45-55% and ash content of 20%, for a well managed deep pit house, i.e. nil value due to the high moisture content. Ventilated deep pit and stilt house types produce manure with 75-80% dry matter and 25%+ ash content, the latter with a value of £3-4 tonne^{-1}, depending upon the exact analysis. Thus in-house fan-assisted manure drying systems and the pilot deep pit manure drying system described earlier (Smith *et al.*, 2001b), at a projected cost of £3.60 tonne^{-1} might offer egg producers assistance in achieving the quality targets required by the power generators, and at reasonable cost.

The scenarios regarding payment for manures outlined above, applied some 7-8 years ago and are based mainly on information passed on by producers. At that time, the Fibrowatt Group would cover the cost of transport and pay producers ca £4 tonne^{-1}. The prices negotiated with manure producers included also the loading of the manure on-farm and this seemed relatively unaffected by distance from the plant. The plants in England were generally prepared to collect suitable litter from within a 50 mile radius, and EPR, from within up to 150 mile radius of the Westfield site in Scotland. The situation does appear to have moved on somewhat from that outlined from several years ago. The energy output from the plants are sold under NFFO agreements, SRO (Scottish Renewable Order) in the case of the Fife plant, which expire in 2013 or 2015. However, the detail of the agreements is not known. It now appears that poultry producers, whilst still providing litter over the same “catchment” areas are receiving rather less favourable terms from the power generators; perhaps ‘cost-neutral’ rather than positive, as in the past. In many cases, this is likely, still, to represent a favourable agreement for producers, because of their shortage of land area on which to spread manures and the necessary transport and spreading costs (to neighbouring farmland) that will be avoided by having the power companies collect the manures instead.

Fertiliser by-product. The ash produced by the incineration process is produced and marketed as a "high quality agricultural fertiliser". "Fibrophos" is a 100% group owned subsidiary, a company dedicated to marketing the ash product. Various grades of ash are blended to provide a range of compound fertiliser analyses, with phosphate content ranging from 12 to 22% P_2O_5. Potash content ranges from 12 to 24% K_2O and the additional benefits include 7% $S0_3$, a liming value expressed as 15% CaO equivalent and a range of trace elements. In 2002/03 Fibrophos sold in excess of 63,700 tonnes of product.

Possible future developments. The costs estimated earlier under the section on manure export (Figure 4.4a&b) offer at least a guide as to likely transport costs, which may need to be considered by producers rather more than in the past. Extrapolating beyond the more local context of manure exports between neighbouring farms, these calculations suggest transport costs of about £10/tonne over the operating 50-mile radius, which is common to most of the plants. One large producer within 40 miles of the Thetford plant commented that the litter is collected in 20t lorries at two loads per day. With typical costs for a lorry of this type, at say £400 day^{-1} (P Metcalfe, personal communication), the projected costs (with 40 tonnes day^{-1} collected) will be £10 tonne^{-1}.

There has been interest in incineration of poultry manure elsewhere in Europe and, in particular, has been actively discussed the Netherlands for >10 years (Willers, personal communication). In fact, it is understood that at least one plant has been constructed (though is yet to operate) in the Netherlands and another is in the planning stages (Table 4.9). Although incineration of pig manures has been researched at the pilot scale, this has not been carried forward beyond the feasibility level and quality of the ash product was said to be disappointing (Anon, 1998c).

Fibrowatt are quoted (Anon, 1998c) as indicating that maximum economic efficiency would be achieved with a plant capacity of 400,000 tonnes of manure per year. The size of the current plant in Scotland (Fife), at 110,000 tonnes annual throughput, suggests that if a new plant of a similar size were to be commissioned in Northern Ireland, it would need to have a catchment capable of supplying at least in that range of annual manure throughput. Based on the a standard of 8.5 tonnes litter per 1000 broiler places, this suggests a minimum requirement of ca 12.9 million bird places in order to justify such investment. The 12.8 million bird places taken from the 2003 June DARDNI Census in N Ireland, suggest that this would just be met.

The farm scale studies in Gloucestershire, which were technically successful, ultimately failed because of the introduction of the increasingly stringent emission standards required by the Environmental Protection Act, 1990, which also led to local authority authorisation requirements. Although combustion efficiency was improved significantly, the increased costs of the flue gas cleaning system could not be justified and the litter combustion equipment was replaced by a coal fired system (Scott, 1999). The initial successful demonstration of the small-scale use of poultry litter as a fuel to heat broiler houses encouraged the unit to consider the litter for CHP (combined heat and power) by installing a single-cylinder steam engine and alternator (FEC Consultants, 1995). Experience with the plant during the period October 1992 – October 1994 was positive, despite downtime due to a major breakdown and plant modification required by HMIP. Cost of the unit was £63,000 to install. Income from the sale of electricity at ca 6.7p kWh^{-1} grossed £32,000 over the two years. Allowing for maintenance costs (£2000), the net savings averaged £15,000 year^{-1}, giving a simple payback period of 4.2 years. The projected electricity sales of > £42,000 over the two years (assuming no excessive downtime) would have allowed payback within 3.2 years. The avoidance of costly downtime and the associated dependence on imported electricity is of key importance to

the viability of farm-scale operations. Consideration should be given to phased poultry production cycles or other arrangements to ensure continuity of fuel supply.
Farm scale combustion is listed among the BAT options described within the EU BREF document for intensive rearing of pigs and poultry (Anon, 2003). The installation described has a design capacity of 200,000 broilers with a projected annual manure input of 2500 tonnes, treating 6-7 tonnes per day. Costs of the plant are summarised as follows:

Table 4.11 Costs of on-farm incineration plant: broiler litter (Anon, 2003)

Cost factor	Cost (€)
Investment (incl filters)	205,751
Dust filters only	76847
Operation (capital, maintenance, etc)	45860
Returns (energy saving, manure)	-59494

Operating costs and returns are calculated on a yearly basis and are said to give a positive balance. For the installation outlined above, with a yearly input of 2500 tonnes of manure, the gross costs are estimated at €18 t^{-1} manure. However, the costs are said to depend very much on the application of a flue gas treatment, which may be too costly for farm scale application.

4.3.12. Soil treatment processing

Another treatment option that seems to have been successfully developed, but, currently, only to pilot scale, is that of soil treatment. The movement of effluent through soil results in a high degree of purification as long as the 'treatment' capacity of the soil is not exceeded. The purification capacity of the soil relates to a combination of physical filtration, chemical reactions (e.g. with respect to phosphate and toxic metals) and biological/microbiological activity in which degradation of substrate compounds and utilisation of the nutrients occurs. One treatment system based on these features of natural soil fertility is the 'Solepur' process developed in Brittany, France (Martinez, 1997). The pilot-scale 'Solepur' system was used to treat pig slurry and is based on three main components:

- managed field (grass or arable) which is drained and hydrologically isolated and to which the slurry is applied. Drainage is collected and passed to:
- reactor for promoting denitrification, via intermediate storage;
- non-managed field to receive the denitrified drainage water.

Large volumes of slurry (ca 1000 m^3 ha^{-1} yr^{-1}) were applied to the managed field, with an average annual nutrient load of 5000kg ha^{-1} N, 1600 kg ha^{-1} P and 1700 kg ha^{-1} K. The process removed 99.9% COD, 99.9% P and ca 90% N from the slurry. The final leachate contained a very low concentration of organic matter, but high nitrate levels, resulting from the oxidation of slurry N in the soil. Whilst the 'Solepur' system retained its capacity for the removal of nutrients and organic matter, over 5 years it appeared that gaseous emissions were in some cases encouraged (Chadwick *et al.,* 1998). Ammonia losses were typical of those from surface applications of slurry at agronomic rates; CH_4 emissions varied considerably according to soil conditions and slurry application rate. Emissions of N_2O were very high following slurry applied in October – at 23% of N applied, in contrast to only 0.17% loss following slurry application to dry soil in June.

Apart from the questionable status of 'soil treatment' systems with regard to existing and impending regulations, the use of this approach, seems inappropriate for the issues currently facing the industry in Scotland and N Ireland.

This approach is possibly of more immediate interest as an option for treatment of dirty water (Chadwick *et al*, 2003 – Defra contract WA0518). In these latter studies, percolation systems constructed on a permeable soil, and an overland flow system constructed using an impermeable soil, have shown considerable promise. Percolation systems working on a continuous basis reduced BOD, MRP and NH_4-N by >90%, at dirty water application rates of 2mm or 8mm. Overland flow systems, working on a batch-flow basis, significantly reduced BOD (>85% removal over 10 days), NH_4-N (>90% removal over 10 days) and MRP (>90% removal over 10 days).

Table 4.12 Summary of key treatment options with estimated impacts on relevant pollutants and a range of applicability criteria

Treatment or management measure	N reduction[1]	P reduction[1]	Volume reduction[1]	Odour reduction[1]	BOD reduction[1]	Pathogen reduction[2]	Energy recovery[3]	Transport costs[3]	Relative cost[3]		Applicability (scale)
									Capital	Running	
Export of manures	3	3	3	1	2	2	0	2	1	1	Local
Storage of solid manures (90 days)[4]	2	0	2	1	1	3	0	0	1	1	Farm
Storage of slurries (draw & fill)	1	0	0	0	0	1	0	0	2	1	Farm
Solid-liquid separation	1	1-3[7]	1	1	1	1	0	0	1	1	Farm
Composting of solid manures	1	0	2	3	1	3	0	1	2	2	Farm/Central
Aerobic treatment of slurries	1	0	0	3	3	1	1	0	2	2	Farm/Central
Anaerobic treatment	0	0	0	3	2	1	3	2	3	3	Central
Manure drying (solids)	1	0	1	1	0	0	0	-1	1	1	Farm
Combustion (solids)	3	3	3	3	3	3	3	3	3	3	Central
Use of treatment additives[5]	1	2	0	2	1	1	0	0	1	1	Farm
Pelletisation (solids)	3	3	2	2	1	1	0	2	3	2	Central
Manure processing	3	3	2	2	3	3	0	3	3	3	Central/Farm
Soil treatment (effluent)[6]	3	3	2	1	3	3	0	0	2	1	Farm

Notes: [1] - reduction in a pollutant as a result of the measure indicated by a +ve value; 1= <25% reduction, 2= 25-75% reduction, 3= >75% reduction

[2] - reduction in pathogens indicated by a +ve value; 1= 1-2 log10 reduction, 2= 3-4 log10 reduction, 3= 5-6 log10 reduction (source Cost-DP project Defra contract ES0121)

[3] – scores for these parameters on a 1= low, 2= medium, 3= high basis. –ve value indicates potential reduction in parameter

[4] – storage of solid manures implying batch storage for a min of 90 days.

[5] – treatment additives covering a range of chemical and biological treatment options

[6] – soil treatment on pilot/experimental basis only

[7] – depending on separation system used, see Table 4.3

5. APPRAISAL OF ALTERNATIVES (TASK 4)

5.1. Appraisal of alternatives

The starting point in dealing with any problem associated with manures at the farm level, at the regional/catchment level or, even more generally at the policy level, should be a definition of what the problem is. This may be related to one or more of a number of possible issues. For example, (i) odour nuisance; (ii) excessive loss of nutrients to surface or ground water; (iii) nutrient enrichment of soils due to poor distribution of manures within the rotation and around the farm; (iv) transfer of animal disease via contamination of surface waters, or (v) difficulties with the economics or logistics of manure management on the farm. Whilst all the above are relevant in varying degrees, in Northern Ireland the problems are particularly acute; there is insufficient land of low nutrient status to accommodate land spreading of manure, and difficulties are compounded by the geographic concentration of intensive pig and poultry units. The situation is less severe in Scotland but of concern in east and central areas where there is a concentration of pig and poultry farms. Sections 3 and 4 above have shown that the problem is complex and that easy solutions are difficult to achieve. A range of technologies have been examined and experimented with, but a major stumbling block for many is scaling up to commercial farm size in a practicable and economic manner. Each of the waste streams examined, broiler litter, layer manure, and pig slurry or FYM present their own challenges, alternatives are therefore considered below for each waste stream.

5.2. Broiler litter

5.2.1. Biomass combustion

The rapid expansion of the broiler industry in Northern Ireland and the early PPC permitting of 40 installations has done much to emphasise the ‘manure problem’ and indeed provide an indication of the environmental difficulties that lie ahead for existing installations. That said, broiler litter probably has the greatest potential for utilisation by alternatives to land spreading. Combustion for energy production is a tried and tested route and currently almost all broiler litter in Scotland is utilised by this means. The stringent controls on incinerator emissions and the fact that renewable energy possibly including combined heat and power is produced mean that using litter as a biomass fuel is an environmentally sound solution. The problem is to a large degree solved in Scotland and provided the necessary investment could be made, a power station of a similar size to the Scottish plant (ca 110,000 tonnes per annum) constructed in a central location in Northern Ireland would also have the potential to remove virtually all the broiler litter from the land bank. This would produce much needed renewable energy with minimal adverse environmental impacts and many positive impacts (Tables 3.6 – 3.8). The data detailed in Section 3 of this study has demonstrated that quantities of broiler litter produced in both Scotland and Northern Ireland are lower than suggested by older ‘standard figures’. Based on that data, virtually all the broiler litter produced in Northern Ireland would be required to fuel a power station of a similar size to the Scottish plant. With the current structure of the industry being strongly organised around a small number of processing companies, it should prove possible to arrange contracts for this purpose.

A large centralised combustion plant need not be the only route for biomass combustion. There is merit in constructing a limited number of intermediate sized combustion units delivering combined heat and power. Advantages of this approach include a spreading of financial risk, an increase in flexibility and a reduction in transport costs if the plants are located near to clusters of broiler farms. As combustion technology has improved smaller installations (2.5 – 5 MW) have become more viable, and provided industry undertakes detailed feasibility studies for their proposed applications this option has much potential.

Possible problems are likely to focus on the high cost of achieving the required emission standards on smaller scale plant. If either large centralised or smaller dispersed combustion solutions were adopted it will impact on other industries in Northern Ireland, although several smaller combustion units could be expected to provide greater flexibility. Mushroom producers currently utilise ca 58,000 tonnes of broiler litter per annum. They would have to find an alternative source for compost manufacture. A switch to layer manure/broiler litter mix could be a possible alternative.

The possibility of co-firing of biomass fuels in coal fired power generation plants has been considered, with some optimism in the case of straw and wood supplies (PowerGen Ltd, 1999). The study concluded that co-firing these biofuels with coal would reduce emissions of CO_2, SO_2 and oxides of nitrogen NO_x. Whilst these studies did not include broiler litter, these sources might also be considered in the light of existing power generation capacity in N Ireland and Scotland. It is important for operators to take into account the application of the Waste Incineration Directive (2000/76/EC) to plant that co-incinerate waste and the associated costs of meeting the Directive requirements. Such costs are likely to preclude co-incineration on coal fired power stations as an alternative use of litter.

Of major importance with high capital cost centralised treatment options is economic stability. Large units may have lower overall processing costs, but are dependant on a number of sources for fuel supply and sales of fertiliser ash, whereas smaller units may be subject to less supply risk if associated with individual businesses. Operational costs for smaller units may however be less favourable. It is important that a subsidised price is received for electricity produced and there is a ready market for the fertiliser ash by-product. Meeting the stringent emission standards required by WID can increase costs to the extent where the operation may struggle to be viable. If smaller schemes are proposed, a critical appraisal of economic factors should be undertaken. A system that works well technically may turn out not to be a realistic option because of high costs, although the increasing importance of environmental issues means that costs associated with manure utilisation need to be considered as an integral part of the business. In future gate fees associated with accepting litter may have to be accepted as a necessary cost.

5.2.2. Compost

Utilising litter for mushroom compost manufacture remains a useful alternative use to land spreading in areas where there is a thriving mushroom industry e.g. Northern Ireland and to a lesser extent in Scotland. The final use of the compost must be borne in mind as if it is returned to land, the benefits are negated to a degree. The nutrient content of mushroom compost is approximately half that of poultry litter. If a centralised power generation facility were to be constructed, it is likely that all broiler litter would be required for incineration, and mushroom composters would require another source of manure. A number of smaller scale combustion plants may therefore allow for greater flexibility.

5.3. Layer manure

5.3.1. Biomass combustion

Layer manure is less suitable for combustion due to a generally higher ash content and lower dry matter content. Modern cage systems are capable of providing dry layer manure provided they incorporate a means of ventilating manure in deep pits or air drying system to dry manure on belts. However drying systems can be expensive to use and in general layer manure is too wet for combustion. Unfortunately, there is some uncertainty within the industry about the future of cage systems as a result of the Welfare of Laying Hens Directive. There is a risk that cage systems may not be permitted after 2012 and given this uncertainty some producers may be reluctant to install new cage systems. It is thought that there will be a significant swing to aviary and free range systems in the UK. This may limit the scope for some alternative uses of layer manure because it is more difficult to dry manure from floor systems. If layer manure was produced at circa 60% dry matter there is potential for quantities to be mixed with broiler litter and incinerated. However the quantities utilised in this way are unlikely to be large enough to remove significant amounts from land spreading.

5.3.2. Drying

In addition to the benefit of reducing ammonia emissions from housing, drying layer manure is likely to permit a greater range of alternative utilisation routes. Composting, pelletising and possibly mixing with litter for incineration would all be easier to achieve with drier manure.

5.3.3. Composting

Composting has potential as an alternative use for layer manure, particularly lower cost methods such as windrow composting. In Northern Ireland if broiler litter was utilised as a biofuel there would be merit in diverting layer manure for use in mushroom compost manufacture although it is recognised that the material may be less easy to work with than broiler litter. With the removal of broiler litter for incineration, the potential exists to remove circa 50k tonnes of layer manure for compost manufacture. This represents a significant portion of layer manure produced in Northern Ireland. In Scotland the mushroom industry is smaller and opportunities for using manure for compost manufacture are more limited, although a small amount is currently used for this purpose.

Increasing attention is being given by local authorities to composting biodegradable municipal waste (BMW). Use of poultry manure as an amendment could be of potential benefit to both composters and the poultry industry. Windrow composting would be the cheaper option but thermophilic in-vessel composting should not be ruled out if poultry manure is used as an amendment for other waste streams. In-vessel composting is likely to prove too expensive solely as a solution for livestock manures, but increasingly stringent legislation on organic waste disposal and treatment places the method high in the waste hierarchy as a best practicable environmental option (BPEO). The process incorporates passive aeration and materials are not turned or agitated. This results in very low emission of dusts, gases such as NH_3 and bio-aerosols. Companies might be encouraged to offer such a composting service to a range of clients and local authorities who need to dispose of organic wastes and would benefit from using poultry manure as an amendment. Barriers to this solution are the capital and operating costs and it is unlikely that plant could be built or operated for poultry manure alone. It would also be essential to ensure that there is a market for the end product and that there were no legislative constraints to its use, particularly as poultry manure when used as an amendment would be only one component of the compost. Whilst the end product is a natural fertiliser and soil improver that can be supplied in bulk or in bags, it is still applied to land, albeit in a safer and more easily handled form. Bulk reduction of about 30% means that the compost can be more easily exported to where it is needed.

5.3.4. Pelletising

Pelletising layer manure to create a fertiliser that is easy to transport and easy to apply accurately is another option that has been successfully undertaken. An advantage of this option is that new and value added markets may be possible, e.g. pelletised manure can be sold in garden centres, other horticultural outlets and for use on amenity land such as golf courses as well as in bulk to farmers and commercial growers.

This option is suitable for dry (circa 80% dry matter) manure and if additional drying costs are to be avoided, it is more suited to cage production systems with air drying of manure incorporated into the process. Future viability could therefore be adversely affected by uncertainty over the future of caged laying systems created by the Welfare of Laying Hens Directive. Although farm scale operations have been tried (Anon. Rural NI 2002) larger scale facilities serving a number of egg producers are more likely to be viable due to economies of scale. Ensuring that there was a market for the product would be vital.

5.4. Pig slurry and FYM

5.4.1. Overview

The number of pigs produced in Scotland and Northern Ireland is similar and the quantities of manure produced are significant. However, in the context of this study, which is examining only those farms above the IPPC threshold size, the manure problem from pig production is less severe than it is for poultry. Accurate information on the number of pig farms subject to IPPC regulation is not available, but it is not thought to be large e.g. circa 20 farms in Northern Ireland, and a similar or slightly greater number in Scotland. Section 4 detailed a number of alternative means of treating or utilising pig slurry and FYM, but practicable options are likely to be more limited and a lot may be achieved with the adoption of best management practises. As discussed in Section 2 previous studies have suggested that the split between FYM and slurry systems will be approximately 50%:50% in Scotland, although in Northern Ireland it is thought that the proportion of slurry systems is around 95%.

5.4.2. FYM and slurry

A range of treatment options were reviewed in Section 4 above and all have applicability in certain situations. In the context of reducing nutrient losses from manure application to land, best management practises and dietary control options have considerable merit. Regulating the nutrient content of diets to match the metabolic requirements of the animal and thus minimise nutrient losses in manure has achieved good results. For example in the Netherlands a compulsory nutrient balance scheme approach resulted in a 20% reduction in nutrient losses over a ten year period (Van der Meer and Van der Putten, 1995). Standard Farming Rules used in the PPC regulations also control diets and this should result in a reduction in nutrient losses, with greater potential for reductions with pigs.

5.4.3. Composting

Alternatives for pig FYM are limited but just as for layer manure, composting could be beneficial in circumstances where there was a serious shortage of land within the vicinity of the piggery. FYM producing pig farms are likely to be less intensive than slurry systems, and in many cases good nutrient management practises will suffice and alternative uses for FYM may not be required. There may even be demand for good quality pig FYM. Composting would also be of benefit in dealing with solids that have been separated from slurry (see below), the main benefits being further reduction in bulk with an end product that is more suitable for a range of applications.

5.4.4. Solids separation

Solids separation has many benefits (see Section 4 above), but of particular importance to IPPC farms that have a limited area of land for slurry spreading is the reduction in nutrient content in the liquid fraction. The solid fraction containing most of the nutrients could be further treated e.g. by composting, and then exported to areas where it can be utilised properly. Equipment for slurry separation is readily available although costs can be high.

This is perhaps why industry uptake has been low (circa 8% of pig farms in the UK). Nevertheless, for farms with insufficient land for slurry spreading this option is well worth considering as part of overall nutrient management planning.

5.4.5. Aerobic treatment

Aerobic treatment is not commonly used in Europe and it has limited potential at present as an alternative option. One of the main benefits of aerobic treatment is a reduction in odours and whilst this may be useful, it is not so relevant if the main requirement is a reduction in nutrient loading. Costs are likely to be the main stumbling block for aeration systems, £7 - £8 per pig place per year would be difficult for the industry to sustain.

5.4.6. Anaerobic digestion

Anaerobic digestion is a tried and tested technology, but the main benefits are when there is a suitable use for the gas produced and a reduction in odours. As an alternative to land spreading to reduce nutrient loading the technique has limited applicability as it is clear that the digestion process does not significantly reduce the volume of the slurry, nor its nutrient content.

5.4.7. Manure processing

The appraisal in Section 4 above demonstrated that attempts at centralised manure processing initiatives have not been successful for a variety of reasons, but often because they proved to be too expensive. Caution is required when suggesting processing as an alternative. Some aspects have shown more promise e.g. the development of a P removal process by precipitation. Further development of this process could provide a worthwhile means of reducing P if this could be done in a cost effect manner. Also, progress of the partial processing (involving drying part composting and conditioning) of manure production through the current Manure Bank in Flanders, is worth monitoring (section 4.3.9).

5.5. Management and treatment options – industry solutions

In the context of costs and farmer preference, a management solution will usually be preferable to a treatment solution. It is generally unlikely that treatment systems can fully pay for themselves, especially if all related costs are included. As a rule, a treatment package will be seen as bringing an overall additional charge to the farmer, because of capital expenditure on equipment or input running and/or maintenance costs. On the other hand, management options may not necessarily add costs over and above those incurred already within an existing (faulty or inefficient) farm system. It follows that there will be a limit to those measures that can be adopted while allowing the business to remain competitive, and a basic rule of “doing the minimum to achieve the objective”, is appropriate. The justification for a more elaborate management option, or perhaps a treatment system, will generally require pressure from environmental regulations as is the case with PPC and NVZ controls, rather than any financial incentive to gain a return. Clearly grant aid would make the economics more favourable.

The overall nutrient balance in N Ireland, taking into account the annual inputs in fertilisers and animal feedstuffs against outputs in agricultural product, is problematic (Foy *et al,* 2002). The calculated annual surplus varied but was 141.6 kg/ha N, 16.5 kg/ha P and 35.3 kg/ha K, during the period 1991-2000. This study has been concerned with minimising returns of pig and poultry manure N and P to land by diversion to other outlets. Whilst this is crucially important for those farms with insufficient land, alternative measures

will not mitigate against the surpluses that arise because of the existing returns from cattle and excessive fertiliser inputs.
A range of treatment technologies that can contribute to mitigation of pollution have been detailed in Section 4. An important consideration should be that the chosen alternative process should be an integral part of the overall manure management system at the farm and should be capable of meeting the clearly defined objectives i.e. a reduction in nutrient loading to land. Technologies are available that can turn slurry into potable water, capable of discharge into a watercourse, but only at enormous cost. What are more certainly required are practical options that meet the needs of the problem without greatly exceeding these. Partial treatment may be appropriate and less expensive.

Whilst still having potential, manure processing is not the solution it was once thought to be in the Netherlands, and centralised processing of manure in the Netherlands has now been discounted in the short and medium term. The Dutch conclude that centralised manure processing is too expensive for pig farmers. That is also likely to be the case in Scotland and Northern Ireland. More recently, experience with on-farm processing in Italy, Spain, Flanders, the USA and even the Netherlands, has been more encouraging, with some suggestion that a co-operative approach linking intensive production units together, may be more sustainable. New technologies such as the use of crystallisation processes for the recovery of P, the use of polymer compounds for improved solids removal and the pelletisation of higher dry matter solids may have merit in the future. Whilst some good performance data are available to support the application of these technologies, the economics are less clear and need more rigorous and robust assessment.

6. CONCLUSIONS

6.1. Broiler litter

There is good evidence from this study that previous standard figures for quantity and nutrient output of broiler litter should be updated. A recommendation for change is made (Table 2.26) with the caution that further work to establish more clearly reasons for the differences in P and K content between Scotland and Northern Ireland would be beneficial.

In Northern Ireland, there is a real possibility that combustion can deal with the surpluses in the medium term, with appropriate investment either in a number of smaller combustion plants for CHP providing power for more local use, or a centralised power generation plant along the lines of those already successfully operating in England and Scotland. The use of litter based poultry manure as a biofuel has been shown to be feasible both technologically and economically, but costs will be influenced by increasingly stringent emissions controls.

Subject to detailed feasibility studies of individual proposals, it is recommended that combustion of broiler litter is adopted as an alternative utilisation for almost all litter produced in Northern Ireland, as it currently is in Scotland.

6.2. Layer manure

There was significant variation in the moisture and nutrient content of layer manure samples investigated in this study, and clear differences from previous standard figures were not apparent. Consequently no recommendation for changes to current standard figures have been made. It is recommended that more detailed studies of the quantity and nutrient content of layer manure are made in the future, possibly in two or three years

hence by which time the effects of standard farming installation rules on installations should be apparent, i.e. greater drying of manure is being achieved.
Variation in moisture content means that layer manure is generally more problematic and greater attention needs to be paid to management options aimed at producing drier manure. This would permit a greater range of alternative uses. Opportunities for composting should be actively pursued e.g. by diverting layer manure to the mushroom industry (particularly if less broiler litter is available for this purpose due to increased incineration). It is also recommended that opportunities are taken to explore the feasibility of greater utilisation of layer manure as an amendment in more centralised systems designed to process a range of organic wastes. An example would be systems processing biodegradable municipal waste, in which layer manure would be an ideal nitrogen rich amendment. Key factors would be establishing markets for the compost taking into account legislative constraints on the end use of the product.

It is also recommended that opportunities for development of manure into a more saleable fertiliser product are pursued, for example by pelletising layer manure and selling into new value added markets. Considerable effort is likely to be needed in developing new markets with care being taken to ensure the nutrient problem is not being transferred to another compartment, or legislative constraints on the end use of the product limit the viability of a scheme.

6.3. Pig FYM and slurry

Samples of pig manure also showed significant variation in nutrient content therefore no recommendations are made for changes to the standard figures. However, as a result of IPPC, changes have been made to pig diets to ensure that crude protein and phosphorus content closely matches animal requirements. This is expected to result in further reductions in N and P content in manures and slurries. It is recommended that more detailed studies are undertaken to evaluate this benefit in two or three years by which time all IPPC pig installations should be operating to standard farming rules.

Best management practice such as solids/liquids separation in slurries has significant benefits and should be implemented. Even further reductions in P are possible as shown by the results from multi-stage processes. Opportunities for further treatment of the solid fraction e.g. by composting should also be pursued.

More novel manure processing techniques such as P removal by precipitation should be further examined with a view to making the process a practicable option for farms needing to reduce the nutrient burden on a limited area of land. Further trials and a more critical appraisal of research would be beneficial.

Ensuring diets match the metabolic needs of the animal can reduce P excretion levels and is an important requirement of the Standard Farming Installation Rules. Benefits of dietary changes are expected to be realised as PPC is implemented throughout the industry.

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