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A STUDY ON FARM MANURE APPLICATIONS TO AGRICULTURAL LAND AND AN ASSESSMENT OF THE RISKS OF PATHOGEN TRANSFER INTO THE FOOD CHAIN

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EXECUTIVE SUMMARY

The number of reported cases of food-borne illness has risen significantly in the UK over recent years, with a six-fold increase in the collective number of gastro-enteritis and food poisoning cases between 1982 and 1998. The main causative agents are bacteria, particularly *Salmonella*, *Campylobacter* and verocytotoxic *Escherichia coli* (VTECs) and viruses, in particular SRSV. In addition, significant levels of human illness are caused by the parasitic protozoa *Cryptosporidium* and *Giardia* and it is likely that in many cases transmission to man is via food or water contaminated with these pathogens.

The reasons for this public health problem are complex and varied. Although it is generally agreed that the best approach to reducing the number of cases is to identify each potential point of pathogen entry into the food chain, and then to implement effective controls. It should also should be noted that pathogen entry into the food chain does not necessarily mean a risk to food safety as there may be further controls implemented before the product reaches the consumer. The application of animal manures to agricultural land is one route by which pathogens may be introduced into the human food chain during the primary food production stage. All the bacterial and protozoan pathogens listed above may be present in animal manures.

This report summarises current knowledge on the levels and prevalence of *Salmonella* spp., *Campylobacter* spp., *Listeria monocytogenes*, *Escherichia coli* O157, *Cryptosporidium parvum* and *Giardia intestinalis* in animal manures, and the factors which affect their survival during storage, in soils and on crops after land application. Using this information along with our knowledge of current farm manure management practices, an assessment has been made of the risks of manure pathogens being transferred into the food chain. The report concludes with a number of practical measures to minimise the risks of pathogen transfer, and outlines recommendations for future research to improve our understanding of these issues.

Pathogens in livestock and farm manures

Large quantities of animal manures are applied annually to agricultural land throughout Britain. In 1997, approximately 68 million tonnes (wet weight) of manure were produced by housed livestock in England and Wales, of which 77% was from cattle, 15% from pigs, 6% from poultry and 2% from sheep. In addition excreta from grazed and extensively reared livestock are deposited on land subsequently used for food production.

A proportion of these manures and excreta will contain pathogenic microorganisms which have the potential to enter food production systems, although there are relatively few data on typical levels.

Cattle. *Salmonella*, *Listeria*, *E. coli* O157, *Campylobacter*, *Cryptosporidium* and *Giardia* have all been found in cattle manures. Data from one study of faecal swabs taken from cattle at an abattoir in North Yorkshire found that around 13% of beef cattle and 16% of dairy cattle produced faeces containing *E. coli* O157.

Pigs. *Salmonella*, *Listeria*, *E. coli* O157, *Campylobacter*, *Cryptosporidium* and *Giardia* have all been isolated from pig manures. *Salmonella* is of particular concern, with 323 reported isolations in pigs in the UK in 1998 and 37% of all isolates typing as multi-drug resistant *S. typhimurium* DT104. Data from one study of faecal swabs taken from pigs at an abattoir in North Yorkshire found that less than 1% of pigs had faeces containing *E. coli* O157.

Poultry. The most commonly found pathogens in poultry manure are *Salmonella* and *Campylobacter*. Whilst *Listeria* may be present, it is not generally thought to be a widespread problem. To date, a number of studies have reported no incidence of verotoxin-producing *E. coli* O157 in UK poultry manures.

Sheep. *Salmonella*, *E. coli* O157, *Campylobacter* and *Cryptosporidium* have all been isolated from sheep manure. Data from one study of faecal swabs taken from sheep at an abattoir in North Yorkshire found *E. coli* O157 in the faeces of 2% of sheep.

Pathogen prevalence and levels are affected by animal age, diet and management, as well as regional and seasonal factors. Shedding of some pathogens appears to be triggered by birth and levels are often higher in the faeces of young animals. Dietary changes may be linked to apparent increases in faecal pathogen levels during spring and autumn when cattle are moved between housing and grazing. Increased shedding of pathogens has also been linked with raising the fibre content of ruminant diets, and with fasting or other forms of stress.

The available literature suggests that *temperature* is the single most important factor which determines pathogen survival times in manures and the wider environment. Pathogens are generally considered to be destroyed after a short time at high temperatures (>55°C) and by freezing. However, even at low to moderate temperatures pathogen numbers will decline over time, especially under very dry conditions or on exposure to UV radiation.

Manure management

There are many different livestock rearing systems currently in practice on British farms. However, the management of most manures can be considered within three main phases, viz:

1. Manure production collection and transfer. During the housing of cattle and pigs, manure can either be handled in a liquid form (slurry) which is usually scraped out of the building or collected in tanks or channels beneath slatted floors, or as solid farmyard manure (FYM) where the animals are reared on straw or other bedding. Sheep manure is almost entirely produced as FYM. Poultry manure from laying hen housing consists of faeces which are usually collected on belts under rows of cages or in large pits beneath the housing, whereas broiler faeces are mixed with bedding (e.g. woodshavings) and usually have a higher dry matter content. Fresh excreta containing pathogens may recontaminate older, previously deposited manures.

2. Manure storage. Manure is removed from livestock housing at variable intervals depending on the management system used. For example, underfloor slurry channels in slatted pig houses can be emptied several times a week, whereas manure from straw-based pig and cattle systems can remain in the house for several months. A relatively large number of farmers spread manures straight to land after they are transfered from the housing, because they do not have adequate storage capacity for liquid manures and the greater convenience of moving solid manures straight from the building to land application. This practice presents a higher risk of pathogen transfer to the food chain, because there is no interim storage period during which pathogen levels can decline.

Slurries are usually stored either in earth-banked lagoons or above-ground circular stores, whereas FYM and poultry manure are generally stacked in field heaps. A single slurry store or solid manure heap may consist of manures from different animal houses and will often contain manures of different ages. The rate of pathogen decline in stored manures will depend on how the stores are managed and ambient weather conditions. Temperature, aeration, pH and manure composition (e.g. slurry dry matter content) have all been shown to influence the rates of pathogen decline during storage.

Pathogen levels gradually decline with increased storage duration, although some have been found to survive in untreated slurry stored for up to 3 months. Pathogen survival times are likely to be longer during winter than in summer, because of the lower ambient temperatures. Solid manure storage for at least 1 month is probably sufficient to ensure elimination of most pathogens, provided that elevated temperatures (at least 55°C) have been reached within the main body of the heap. However, there is a small risk that some pathogens may still survive in cooler exterior or drier parts of manure heaps. The turning and composting of manures to thoroughly mix and promote higher temperatures should ensure effective pathogen kill. Where solid manures are not actively managed, elevated heap temperatures may not be achieved and a longer storage period of 3 months is probably required to decrease pathogens to acceptable levels.

Anaerobic and aerobic slurry treatment systems can reduce the numbers of slurry pathogens (log 2 reductions have been measured in anaerobically digested slurries). However, the enormous capital costs involved in equipping farms to treat their slurries

would be extremely difficult for the livestock industry to finance and would only be partially effective in reducing pathogen loads. A more appropriate investment for the industry would be to increase slurry storage capacities which has the dual benefit of reducing pathogen levels and a potential for improved nutrient management practices.

3. Land spreading. Most animal manures are recycled to agricultural land providing an important source of plant nutrients and organic matter. Slurries may be surface applied (by broadcasting or band spreading) or injected into the soil. Band spreaders and injectors carry less risk of aerosol generation, but the slurry is likely to dry more slowly and be less exposed to UV radiation, increasing the potential for pathogen survival. At present, broadcast spreading is the most widely used slurry application technique (>90% of slurry is spread this way), however, pressures to reduce ammonia and odour emissions are moving the industry towards band spreading and injection techniques. All solid manures are surface applied using rear or side discharge spreaders. Research on sewage sludge has found that pathogen survival following frequent, low rate dressings was lower than infrequent, heavy dressings. The application of manures at agronomically required rates, as advised in the MAFF Water Code, is likely to result in lower pathogen survival rates than heavier 'disposal' applications.

In addition, cattle and sheep spend a large part of the year grazing pasture. Similarly, land may be used for outdoor pig farming as part of an arable crop rotation and ruminants may be wintered on arable stubble crops (e.g. sugar beet tops). Under such management practices excreta containing high levels of pathogens may be deposited directly onto the land. At present no advice is provided to farmers on recommended minimum time intervals between the removal of livestock from a field and the subsequent harvest of crops grown on the land.

Pathogen survival times are likely to be longer in soils than on the surface of crops, with some pathogens still being viable in the soil several months after manure spreading or excretion onto grazed land. As both animals and humans may ingest soil adhering to crops, there must be a sufficient interval between manure application and the harvest of crops (particularly those likely to be consumed raw) or resumption of grazing, to allow pathogen levels to decline significantly.

Current guidance

The MAFF Codes of Good Agricultural Practice for the Protection of Water, Air and Soil provide sound practical guidance on the management of manures to minimise the risk of pollution from minerals (particularly nitrogen and phosphorus) and organic nutrients. Although the codes were not been designed to control pathogen spread, adherence to the advice will reduce the risks of pathogen transfer into the wider environment. However, there is some justification for strengthening and refocusing some of the recommendations, particularly those relating to the storage of manures and manure spreading practices, to further reduce the risks of pathogen transfer to the foodchain.

The 'Safe Sludge Matrix' for biosolids application to agricultural land provides clear guidance on the minimum acceptable level of treatment for any sewage sludge based product which may be applied to different crops or rotations. The Matrix has given the retailers and Food Industry reassurance that sewage sludge reuse on agricultural land is 'safe'. However, there are clearly differences in the ability of farmers to treat animal manures and the capacity of the water industry to treat sludge with centralised sewage collection and treatment facilities . Therefore measures recommended in the safe sludge matrix are not appropriate for addressing the microbiological risks from animal manures.

Organic farming

An increasing number of British farmers are converting to organic food production. Pathogen levels and survival in manures produced in organic systems may be different from those in conventional systems. Restrictions on the use of antibiotic feed supplements and therapeutic antibiotics by organic farmers may mean that pathogen levels in organic manures are higher than those from conventionally reared livestock (although there is currently only limited data to support this hypothesis). However, the Soil Association recommendations for manure storage and treatment (i.e. solid manure composting and slurry aeration) on organic farms, are likely to lead to enhanced reductions to the levels of pathogens in stored manures which are destined to be spread

to land. At present there is insufficient information to state categorically whether the risk of pathogen transfer from organic farms differs significantly from the risk associated with conventional farming practices.

Recommendations for farmers and growers

This review has collated the available data on pathogen levels and behaviour in animal manures and the soil and crop environments. Combining this with current knowledge of manure management practices on British farms, we have identified current practices where there are risks of pathogen transfer into the food chain. The key recommendations for farmers and growers to reduce these risks are given below.

1. Where practically possible, slurries should be stored prior to land application for at least 1 month and preferably for 3 months, to provide a sufficient length of time for pathogen levels to decline. Where more than one slurry store is available on farm, these should be filled and emptied in batches, to avoid the recontamination of previously stored manures with fresh material.

2. Solid manures should be stored for at least 3 months prior to land spreading. Active manure management (e.g. by turning and mixing) should be encouraged to promote elevated temperatures (at least 55°C) during composting. Where this occurs a storage period of 1 month is probably sufficient to ensure the elimination of most pathogens.

3. As there are increased shedding rates of some pathogens from certain classes of stock (e.g. young animals), consideration should be given to handling these manures separately and ensuring that they are stored for long periods or composted.

4. Farmers should be encouraged further to follow the guidelines in the MAFF Water Code on manure storage and land application practices, as this will have the additional benefit of preventing pathogens directly entering watercourses from point and diffuse pollution sources as well as reducing chemical pollution.

5. If farmers follow current MAFF advice on the use of low-trajectory slurry spreading techniques, this probably provides sufficient protection against the risk of direct pathogen inhalation via aerosols, although adjacent crops, grazing land, livestock and waterways could still become contaminated if there is aerosol drift.

6. Export of manures from the producer farm creates a potential route for pathogen spread to neighbouring land, particularly if the manure has not been stored or treated beforehand. It is recommended that recipient farmers satisfy themselves that any imported manure has been managed appropriately, and where there is doubt, to treat the manure accordingly.

7. We recommend that consideration is given to providing special guidance to farmers and growers using manures for the production of ready-to-eat crops (e.g. salads) because of the greater risks to food safety. Manures should never be applied directly to ready-to-eat crops and an interval of at least 6 months should be observed between manure spreading and harvest of the crop.

8. Where ready-to-eat crops are grown on land previously used for livestock grazing or foraging, at least 6 months should elapse before harvesting the crop.

9. We recommend that farmers are encouraged to follow current advice to apply manures to cut grassland rather than grazed pastures. Where application to grassland during the grazing season is unavoidable, farmers should be advised to store manures for at least one month before land spreading and to leave pastures ungrazed for at least one month or until all visual signs of manure solids have disappeared.

10. It is likely that stock grazing pastures contaminated by pathogens present in the faeces of other herd members will also become infected. Farmers should be encouraged to separate obviously ill animals, and where possible, the uninfected livestock should be moved to fresh pastures.

11. It is recommended that when livestock with an unknown disease history are brought onto a farm, where possible, their manures should be stored separately for as long as is practicable.

Recommendations for MAFF

It is evident that contamination of food by pathogens can occur during primary production. Some of these pathogens could originate from animal manures and may contribute to cases of human food-borne illness. It is not possible at present to undertake a comprehensive risk assessment in order to estimate the importance of this contribution and to address this two areas need to be tackled:

i. Appropriate on-farm control measures need to be introduced which have been designed to minimise pathogen transfer from animal manures into food. These measures must take account of the agricultural and environmental implications. In order to facilitate these control measures, consideration should be given to producing guidance documents which supplement those currently available i.e. the MAFF codes of Good Agricultural Practice. These supplements should take full account of both the microbiological and chemical risks associated with the spreading of livestock wastes.

ii. Practical, farm-based research should be performed to provide the data necessary to fill gaps in our understanding of pathogen movement and survival in agricultural environments and our suggestions are detailed in section 8 of this report. MAFF have already begun to address the shortfall of information under the FS35 programme. Thereafter, complete risk assessments should be developed which include additional controls targeted at reducing the hazard in high-risk areas.

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1. INTRODUCTION

In recent years, there has been a significant increase in the rate of foodborne human illness. Whilst this trend is global, the reported collective number of cases of gastro-enteritis and food poisoning cases in the UK increased six-fold between 1982 and 1998 (Jones 1999). This increase was largely the result of rising infections by *Salmonella* spp. and *Campylobacter* spp.,. Of particular concern are cases caused by verocytotoxic *Escherichia coli* O157 which although relatively low in number, can be particularly serious where they occur (Jones 1999). Parasitic protozoans can also cause human gastro-intestinal infections, particularly *Cryptosporidium parvum* and *Giardia intestinalis* (known as *G. lamblia* in the USA). In many cases, it is probable that these protozoans are transmitted to man via water but it seems likely that some cases are foodborne e.g. salad crops irrigated with contaminated water. The potential of water-borne protozoa to cause human illness on a grand scale was illustrated in the early 1990s when over 400,000 North American citizens were infected by *Cryptosporidium parvum* (Mackenzie *et al* 1994).

The reasons why food poisoning and gastro-enteritis caused by food-borne microorganisms continue to be a major public health issue in the UK are varied and complex, and pathogens can enter the food chain and in some cases multiply at any point. It is generally accepted however that the true number of cases are considerably higher than official statistics mainly because many cases go unreported.

To address the problem, contamination of food by human pathogens needs to be prevented or at least minimised wherever possible. The most effective means of doing this is to identify every potential point in the entire food chain where contamination can occur and then implement effective controls. This 'plough to plate' approach is now widely accepted as the best way forward and forms the basis of a considerable amount of current food safety research.

Agricultural production is the source of the majority of our foods, therefore, prevention of pathogen entry into the food chain on farms should make a major

contribution to the battle against food-borne illness. One agricultural activity which poses considerable potential risk is the application of organic manures containing pathogenic microorganisms to land used for food production. Therefore, there is a need to review this activity, assess the potential microbiological risks and implement suitable controls to minimise these risks.

Large quantities of animal manures are recycled to agricultural land in the UK as the most economical and environmentally friendly means of treatment and reuse. These materials have a fertiliser (NPK) value and can help maintain soil quality and fertility. However, animal manures frequently contain enteric pathogenic microorganisms (Jones 1999) and land spreading is likely to lead to pathogen entry to the food chain. Therefore, controlling levels of pathogens in wastes at the point at which food is harvested, should help to reduce their prevalence.

Routes of transmission will vary, for example; by contamination of water supplies (MacKenzie *et al*. 1994) and then either onto food crops by irrigation or into livestock via stock drinking; by contamination of milk and animal feedingstuffs; through direct ingestion of spread wastes adhering to leaf surfaces (Jones 1986), on soil particles (Fenlon *et al*. 1996) and where wastes/soil adhere to harvested crops (e.g. for salad crops) (Mawdsley *et al*. 1995). The risks of pathogen transfer from organic wastes to food has been recognised by a number of influential bodies including the American FDA (Anon 1998a).

Over recent years various guidance documents on the recycling of organic wastes to land have been produced for farmers, waste contractors and interested parties, in particular the MAFF Codes of Good Agricultural Practice for the Protection of Water (MAFF, 1998a), Soil (MAFF, 1998b) and Air (MAFF, 1998c) and the DoE Code of Practice for Agricultural Use of Sewage Sludge (DoE, 1996) which implements EU Directive 86/278/EEC regulating the use of sewage sludge on agricultural land. In addition, there have been advisory booklets produced specifically on the management of livestock manures. All these documents largely have concentrated on measures to reduce environmental pollution and maximise soil fertility and have not fully addressed the issue of controlling the spread of pathogens, although the Sludge Code

and EU Directive provide guidance on management practices to minimise risks to public and animal health arising from pathogens in sludge. More recently UK retailers, via the British Retail Consortium, have raised concern over the microbiological risks from applying sewage sludge to agricultural land. In response, a 'Safe' Sludge Matrix was developed which specifies that only treated sludge products may be applied to land used for food crop production and recommends minimum time periods between the application of sludge and crop harvest. However, there are clearly differences in the ability of farmers to treat animal manures and the capacity of the Water Industry to treat sludge with centralised sewage collection and treatment facilities. Therefore, the measures recommended in the 'Safe' Sludge Matrix may not be appropriate for addressing the microbiological risks from animal manures.

Two recent reports from the House of Commons (Anon 1998a, Anon 1998b) and two government reports (Carrington *et al*. 1998a, Carrington *et al*. 1998b) on the risks and hazards relating to the agricultural use of sludge have raised the issue of microbiological risks from recycling wastes to land. In response, the Government made a commitment to review the practice with a view to implementing appropriate control measures.

The research detailed in this report reviews current on-farm animal manure management systems and identifies those areas posing the greatest risk in terms of pathogens in animal manures transferring into the food chain. All relevant guidance documents, including those for sewage sludge, are assessed in terms of their effectiveness in controlling the spread of pathogens in farm animal manures into the human food chain. It concludes by making a series of recommendations as to what practical measures would be likely to minimise pathogen transfer taking full account of the agricultural and environmental implications.

Finally it is important to note that just because pathogens enter the food chain on the farm they may not necessarily be a risk to food safety because of controls implemented before the product reaches the consumer's plate. The remit of this report is limited to assessing the risks of pathogen transfer. However, comment is made

where these are obvious risks to food safety; for example, the contamination of salad crops likely to be eaten in the raw state.

2. LEVELS AND SURVIVAL OF HUMAN PATHOGENIC MICROORGANISMS IN ANIMAL MANURES

2.1 Introduction

Livestock can harbour a number of human pathogens in their gut and consequently their excreta may also contain these pathogenic organisms (Pell, 1997, Mawdsley *et al*. 1995). However despite the potential risk that animal manures represent in terms of pathogen transfer to the human food chain, there is presently little pertinent information on either the prevalence or levels of human pathogens in livestock manures in the UK or on their survival during storage and following land spreading. This section of the report summarises information available in the published literature.

2.2 Campylobacter

In 1997, *Campylobacter* was recorded as the cause of c. 50,000 (62%) of the total 85,000 reported cases of gastrointestinal infection in the UK (Jones 1999). This trend was mirrored outside the UK, and members of the genus *Campylobacter* have become established as the most common human gastro-enteric pathogen throughout much of the developed world (Thomas *et al*. 1999a). In an outbreak in England caused by wild bird droppings contaminating a potable water tank, the minimum infection dose for humans was determined as 500 viable cells (Davis *et al*. 1999). *Campylobacter* spp. are widely found in the intestinal tract of many animals especially poultry (Jones *et al*. 1999, Stanley *et al*. 1998, Koenraad *et al*. 1995) indicating that animal manures represent an important potential source of this bacteria on British farms.

Solomon and Hoover (1999) reported that *C. jejuni* was extremely susceptible to a wide variety of antimicrobial treatments, food processing methods and environmental stresses and were perplexed by what they described as the "*Campylobacter* paradox—How can an organism of such limited hardiness and growth capabilities be responsible for an ever-increasing level of human foodborne disease?". Nevertheless, *Campylobacter* has been shown to be well adapted for survival in aquatic environments (Thomas *et al*. 1999b). Although survival periods >4 months have been reported for *Campylobacter* in sterilised river water at 5^{o}C, a more representative average of 15^{o}C limits survival to between 40 and 60 days (Thomas *et al*. 1999b).

Campylobacter are very heat sensitive and a ten-fold reduction in numbers takes approximately 6 seconds at 60°C. The campylobacters that cause enteritis in man will not grow below 30°C and the optimum growth temperature of these strains is 42°C and the maximum 47°C. As with other infectious pathogens, campylobacters survive better under cool conditions than at ambient temperatures. Campylobacters are also very sensitive to drying but there is some evidence that they may still survive in viable non-culturable forms (section 2.13.1). Campylobacters are acid sensitive and will not grow below pH 4.9. *Campylobacter jejuni* grows best in the pH range 6.5-7.5 and has a pH range of 4.9 to 9 0. Campylobacters are very sensitive to salt; 2.0% salt is sufficient to inhibit their growth, even under otherwise optimum conditions.

2.2.1 *Campylobacter* in cattle manure

Stanley *et al.* (1998a) reported the incidence of *Campylobacter* infection in beef cattle slaughtered in an abattoir in Preston (Lancashire, UK) over a 3 year period as 89.4% (n=360). The abattoir processed cattle from North Wales, SW Scotland and NW England, and mean levels of *Campylobacter* present in faeces are given in Table 1.

Table 1. Average and peak levels of *Campylobacter* present in infected cattle faeces in North Wales, SW Scotland and NW England between 1993 and 1995.

Animal type	Average MPN/g fresh faeces	Peak MPN/g fresh faeces
Beef cattle at slaughter	6.1×10^2	2.4×10^7
Dairy herd	69	ND
Calves	3.3×10^4	2.4×10^8

ND: Not determined.

Further work by Stanley *et al* (1998b) demonstrated seasonal fluctuations in the levels of viable *Campylobacter* in dairy cattle slurry stored in tanks on Lancashire farms. Typical values were determined as 6 CFU/g slurry in May and June, rising to 117

CFU/g in November and December. Extensive investigations revealed no correlations between levels of *Campylobacter* and air temperature, hours of sunshine or rainfall. It is likely however, that lower winter temperatures would favour increased *Campylobacter* survival, as it has been shown that *Campylobacter* decline more rapidly at 14^{o}C than at 4^{o}C (Stanley *et al*. 1998b).. There is little information on likely rates of decline during storage. However, Stanley *et al*. (1998a) reported that aeration of stored dairy slurry for three days caused a reduction in *Campylobacter* levels from 363 CFU/g slurry to 128 CFU/g slurry. These authors also observed that campylobacters were readily detected in samples of matured cattle slurry and in composted bedding. In addition, (Kearney *et al*. 1993) reported that mesophilic anaerobic digestion had little effect in reducing the numbers of *C. jejuni* in cattle slurry.

2.2.2 *Campylobacter* in pig manure

There is very limited information on the prevalence of *Campylobacter* on British pig farms. However, a few publications from other European countries indicate that *Campylobacter* carriage is certainly possible in pigs and may therefore pose a potential risk in the UK.

Weijtens *et al*. (1997) demonstrated the horizontal transfer of campylobacter from mothers and the immediate farm environment to piglets. In a later study, Weijtens *et al*. (1999) sampled eight individual fattening pigs, and their maternal sows by rectal swab for a period of 15 weeks. All of the piglets cultured positive for *Campylobacter* during the sampling period, although some animals shed *Campylobacter* only intermittently. Further analysis using PCR revealed that there was considerable diversity in the Campylobacters, with 28 distinct clonal variants identified amongst the pig population.

In Norway, high rates of *Campylobacter* carriage of almost 58% were found in slaughtered pigs sampled from their gall bladder and bile (Rosef 1981). Svedhem and Kaijser (1981) reported that 95% of pigs sampled at Dutch slaughterhouses carried

Campylobacter. However, it was later reported that the serotypes and biotypes of pig and human *Campylobacter* isolates in Rotterdam were infrequently related to each other, suggesting that pigs were not an important reservoir of human *Campylobacter* infections (Banffer 1985).

2.2.3 *Campylobacter* in poultry manure

Although poultry farms are frequently infected with *Campylobacter jejuni* and *Campylobacter coli*, limited research has been performed to determine the fate of these pathogens shed in poultry faeces. Poultry appear to tolerate high levels of *Campylobacter* in their gut, and several studies have shown that levels in faeces can rise to between 10^4 and 10^7 CFU/g faeces with no apparent ill effects to the birds (Doyle 1984, Stern *et al*. 1988, Prescott and Mosch 1981).

A recent study investigated the rate of colonisation of turkeys with *Campylobacter* (Wallace *et al*. 1998). Newborn poults were generally free of *Campylobacter* infections, however colonisation occurred rapidly. Within 2 weeks carriage was 100% for three of the broods studied and within 3 weeks 100% for the remaining two broods investigated. The poultry house environment, litter and drinking water harboured large ($>10^4$ CFU/g material) numbers of the pathogen within one week of the arrival of the uncolonised turkey poults.

2.2.4 *Campylobacter* in sheep manure

Campylobacter has been isolated from the intestines of slaughtered sheep in the UK, and the in-herd rate of carriage often appears to be high. Jones *et al.* (1999) reported that the most common species in sheep was *Campylobacter jejuni*, present in concentrations of up to 2×10^5/g faeces. Other closely-related forms of thermophilic *Campylobacter* including *C. coli* and *C. lari* tend to be found less (Jones 1999). Jones *et al*. (1999) also found that *Campylobacter* levels in sheep faeces were influenced by season with high rates of shedding in ewes appearing to be triggered by birth resulting in rapid colonisation of new-born lambs.

Information concerning the rates of survival of *Campylobacter* in sheep faeces is limited, but the organism was still viable in samples gathered fresh and allowed to dry outdoors for at least 3 days (Jones *et al*. 1999). There is evidence that dietary influences on faecal mass and the rate of digestion can effect both *Campylobacter* survival and shedding (Jones *et al*. 1999). Furthermore, *Campylobacter* survival rates decreased in faeces with a low dry matter (Jiang and Doyle 1998). It is probable that correlations between faecal mass and *Campylobacter* survival are at least partly a consequence of slower rates of dehydration for faeces of larger mass.

2.3 Listeria monocytogenes

The Public Health Laboratory Service reported the incidence of food poisoning in the UK in 1997 caused by *Listeria* spp. as c. 130 cases (Jones 1999). Despite the relatively small number of cases, listeriosis is considered a major problem because infection in humans results in severe neurological trauma and death in around 25% of cases (Jones 1999). *L. monocytogenes* has been shown to utilise a nutritionally diverse spectrum of energy sources and can grow over a wide range of temperatures, pH ranges and osmotic potentials (Bille and Doyle 1991). The organism is found in high numbers in poorly fermented silage (Grant *et al*. 1995), and is readily isolated from the rhizosphere (Dowe *et al*. 1997). Although *Listeria* spp. are ubiquitous in the rhizosphere, there is evidence that natural incidence is higher in soils that have not been disturbed for long periods of time (Dowe *et al*. 1997).

2.3.1 *Listeria monocytogenes* in cattle manure

A two-year epidemiological study examining almost 4000 faecal samples in 250 dairy herds in the USA found that *L. monocytogenes* was most prevalent in winter, and that there was a strong positive correlation between the presence of the organism and the feeding of silage to cattle (Pell 1997).

The viability of *L. monocytogenes* in beef cattle slurry has been shown as temperature-dependent (Kearney *et al*. 1993). When stored at temperatures of 17^{o}C, *L. monocytogenes* inoculated into slurry showed a decline from 3.2×10^{6} CFU/ml slurry to 4×10^{4} CFU/ml slurry over a period of 84 days. The average time taken for a reduction of one order of magnitude in viable numbers ($x\mathrm{T}_{90}$) was 29.4 days. However, storage of an identical sample at 4^{o}C caused no net change in the number of viable bacteria. The authors speculated that the ability of *Listeria monocytogenes* to grow at 4^{o}C may explain why the population did not decline. Similar periods of survival for *L. monocytogenes* in cattle slurry have also been reported by Dutch researchers (vanRenterghem *et al*. 1991) who found that viable organisms could be isolated after 60 days storage at 15^{o}C.

Kearney *et al* (1993) investigated the reduction in pathogens during batch and semi-continuous anaerobic digestion of inoculated slurry. For *L. monocytogenes* strain LM1, semi-continuous digestion caused a small increase to the xT_{90}, whereas batch digestion lowered it from 29.4 days to 12.3 days. The authors noted that, apart from anaerobic digestion-resistant *C. jejuni*, the rate of decline of *L. monocytogenes* under all of the storage conditions investigated was significantly lower than that observed for *S. typhimurium*, *E. coli*, and *Yersinia enterocolitica*.

2.3.2 *Listeria monocytogenes* in pig manure

There is currently limited information available on either levels of *Listeria* or their survival in pig manure. There is no question however, that there is an association between pigs and *Listeria*, and whilst little specific data exists on shedding in pig manures to porcine wastes, anecdotal data suggests a very low-level of occurrence.

An American study investigated the occurrence of *Listeria* in 932 slaughtered pig carcasses, and despite the rupture of a number of intestinal tracts during processing, was unable to detect *Listeria* on any of the carcasses (Miller *et al*. 1997). Similarly, a German study concluded that *Listeria* was not the cause of abortion in 1113 samples of pig abortive material submitted for (Lehmann and Elze 1997).

Conversely however, a second German study (Barrow *et al*. 1996) found that *L. monocytogenes* was present in 5.9% of 34 pig faecal samples analysed and isolated from 17.9% of the 84 pork carcasses sampled. In addition, Borch *et al.* (1996) reported that a number of pathogens including *Listeria* were endemic in Danish pig slaughterhouses, and recommend early removal of the intestines as a precautionary measure to prevent carcass contamination by *Listeria*.

2.3.3 *Listeria monocytogenes* in poultry manure

Barrow *et al*. (1996) reported that in Germany, *L. monocytogenes* was present in 8% of 100 samples of hen's faeces analysed. The fate of *Listeria* in poultry manure was investigated (Himathongkham and Riemann 1999b) who found that the numbers of *L. monocytogenes* in fresh chicken manure increased by between one and two log units over two days. Over a further six days however, whilst there was significant decrease in the numbers of viable *E. coli* O157, and *S. typhimurium*, the number of viable *L. monocytogenes* remained unchanged. During the total eight day period there was a sustained rise in pH from 7.2 to almost 9.5, caused by a natural conversion of nitrogenous compounds to ammonia.

2.3.4 *Listeria monocytogenes* in sheep manure

Despite a widely acknowledged association between *Listeria* and sheep in the UK and Europe generally, there is very little data which describes either levels of this pathogen or its survival in sheep manures. Generally there is a lack of information on pathogens associated with sheep manures, and this is most likely a consequence of the current sheep farming practices where sheep are reared outdoors on land usually unsuitable for other purposes. Thus, for the majority of the year sheep manures pose little risk of pathogen transfer , and subsequently have not been the subject of applied research.

However, *Listeria* does cause problems in sheep and correlations between *Listeria* colonisation and abortion by pregnant ewes have been well described (Lehmann and Elze 1997, Buxton and Henderson 1999). Furthermore, *Listeria*-induced encephalopathy of sheep neural tissues and colonisation of sheep cerebra-spinal fluids by *Listeria* has been reported (Rebufatti *et al*. 1996).

Nash *et al.* (1995) report an outbreak of Listeriosis in sheep fed on silage in Illinois, USA. During the outbreak, 3.1% (29/936) of all ewes and 1.3% (17/1262) lambs in the flock died. Although little specific information was given concerning colonisation prevalence in the flock, one conclusion of the study was that there was no difference to the risk of infection between animals of different gender, age or breed.

2.4 Escherichia coli serotype *O157*

The early 1980s, saw the emergence of *Escherichia coli* strains which produce cytotoxins similar to those produced by *Shigella dysenteriae*. This group of related cytotoxins are commonly referred to as Shiga-like toxins or type 1 verotoxins (VT1), as a consequence of their lytic action on the Vero cell line. Type 2 verotoxins (VT2) have a similar mechanism of action to VT1, but are antigenically distinct. Verotoxin-producing *E. coli* (VTEC), which harbour genes for either, or both VT1 and VT2, have become an important food-borne cause of haemolytic-uremic syndrome and lytic colitis in humans. Although toxin secretion is most commonly associated with *E. coli* serotype O157, other serotypes of *E. coli* including O91, O26 and O111 have been reported to produce cytotoxins (Beutin *et al*. 1993, Samadpour *et al*. 1994). Of great concern are reports that lytic Shiga-like toxins are found in phage genomes and can thus be easily transferred between coliforms (Plunkett *et al*. 1999).

Dairy and beef cattle are the most important reservoirs of *E. coli* O157 (Chapman *et al*. 1997, Zhao *et al*. 1995, Tuttle *et al*. 1999, Bolton *et al*. 1999), and it has been estimated that 1-4% of UK cattle herds are infected, with a greater prevalence in dairy herds compared with beef herds (Matthews *et al*. 1997). A survey of meat products including pork, poultry and lamb provided evidence that other animals may also harbour a spectrum of toxigenic coliforms (Doyle and Schoeni 1987, Samadpour *et al*. 1994). A further study confirmed the natural presence of VTECs in the gut of sheep and goats (Beutin *et al*. 1993), but was unable to find any in 144 tested chicken manure samples. Although VTECs were identified in pig manures, the incidence was far lower than for cattle manures.

E. coli O157 is heat-sensitive and is destroyed by the same temperature that is recommended to eliminate *Salmonella* and *Listeria* (70°C for 2 minutes). The minimum pH for growth is thought to be pH 4.5, but some strains can survive in low pH environments (Ryu *et al*. 1999). Temperatures below 5°C prevent growth of VTEC, although any organisms present may survive for several weeks.

Studies with generic *E. coli* have shown that survival in water is influenced by many factors including temperature, exposure to light, nutrient levels, competition and predation (Mawdesley *et al.* 1995), although it is not clear whether *E. coli* O157 respond in the same way to all these influences.

However, the ability of *E. coli* O157 to contaminate food and cause human illness was made very clear in a recent report from the United States. Hilborn *et al*. (1999) tracked the epidemiology of a multi-state outbreak of *E. coli* O157. The outbreak was traced back to a single grower-processor who kept cattle near a field used for the production of mesclun lettuce. The report concluded that US lettuce production practices should be examined and monitored for microbiological safety.

2.4.1 *E. coli* O157 in cattle manure

E. coli O157 occurs widely in cattle throughout the US, and levels in cattle faeces from a survey of 50 herds in 14 states were found to range from 10^2 to 10^5 viable cells/g faeces (Zhao *et al*. 1995). There has been no similar systematic survey of *E. coli* O157 numbers in cattle manures produced in the UK. However, in Scotland in 1992/3 Synge and Hopkins (1996) detected VTEC O157 in 0.25% of cattle samples, and in England and Wales in 1994/5 Richards *et al* (1997) found VTEC O157 in 0.83% of cattle faeces samples. A study of rectal swabs from beef carcasses at an abattoir in South Yorkshire found *E. coli* O157 in 4% of samples (Chapman *et al* 1993), whereas in 1995/6 *E. coli* O157 was found in 13.4% of beef cattle and 16.1 % of dairy cattle, with monthly prevalence in cattle ranging from 4.3-36.8% (Chapman *et al* 1997).

Several authors have reported higher *E. coli* O157 prevalence or shedding rates for dairy cattle compared with beef cattle (Wang *et al*. 1996; Matthews *et al*. 1997; Chapman *et al*. 1997). Mechie *et al* (1997) found that shedding was low (0.9%) amongst lactating cows, but high (14.3%) in heifers. Other authors have reported higher prevalence amongst weaned calves (Hancock *et al*. 1994; Zhao *et al*. 1995) or younger animals (Wang *et al*. 1996).

The distribution and prevalence of *E. coli* O157 on a UK dairy farm whose cattle harboured the organism asymptomatically was investigated by Porter *et al*. (1999). Solid and liquid manures were found to harbour toxigenic *E. coli* O157, as did the farm pond. Although grass, soil, a second pond and temporary surface waters were also found to contain O157, the strains isolated did not contain either the VT1 or VT2 genes. VT1 genes were the most prevalent of the VTEC population on the farm.

A further UK study over a fifteen month period examined the relationship between time of year and the shedding of *E. coli* O157 in a dairy herd known to be associated with human infections (Mechie *et al*. 1997). Since individual numbers of organisms in samples were not determined, the data describes only the number of animals shedding in the herd above the detection limits of the culture procedure. The results revealed strong correlations between the season and the percentage of the herd actively shedding *E. coli* O157, with highest shedding levels observed between May and August, and a smaller peak in November after housing. Similar seasonal patterns in shedding were found by Chapman *et al.* (1997) and Shere *et al.* (1998), with excretion rates highest in spring and late summer.

Dairy cattle bedding has been shown to support high *E. coli* (1×10^9) counts (Blowey, 1994). Woodshavings, sand, shredded paper and sawdust can all be used as bedding materials, with sand supporting the lowest *E. coli* growth in a range of materials tested by Francis (1989) and sawdust supporting the greatest coliform population (Table 2).

Table 2. Coliform populations supported by different types of cattle bedding.

Type of bedding	Total coliform count
Sawdust	5.2×10^7
Shavings	6.6×10^6
Straw	3.1×10^6

Source: Rendos *et al.* (1975)

Cray *et al*. (1998) working in the USA, found that calves fasted before inoculation with 1×10^{10} CFU were more susceptible to infection, with some animals shedding significantly more *E. coli* O157:H7 than those regularly fed prior to inoculation. There was no effect on *E. coli* O157:H7 shedding rates when calves were fasted post-inoculation. Brownlie and Grau (1967), Grau *et al*. (1968) and Anon (1995) have all reported previously that *E. coli* incidence and numbers increased in cattle faeces after dietary and/or transportation stress.

Wang *et al.* (1996) seeded cattle faecal samples with either 10^3 or 10^5 CFU/g and incubated them in stomacher bags over a range of temperatures for extended periods of time. The study found that there was no increase in *E. coli* O157 numbers in cattle faeces stored at 5^{o}C, although the organism could still be cultured after 70 days. Samples seeded and stored at 22^{o}C showed an initial 100 to 1000-fold increase in cell numbers, before a sustained decline. Following incubation at 22^{o}C the bacteria remained viable for 49 and 56 days for the lower (10^3) and higher (10^5) inocula, respectively. Increasing the storage temperature to 37^{o}C caused a greater rate of dehydration of the sample and subsequently *E. coli* O157 was only detected for 42 days.

A similar study (Bolton *et al*. 1999) used higher initial inocula of 10^{8-9} CFU/g faeces. Samples were either incubated at 10^{o}C or placed outside and the temperature allowed to vary with the ambient conditions. An attempt to counter excessive dehydration of the manure was made by use of closed plastic boxes, and comparisons were made with samples which had been spread onto grass pasture. The results showed that for samples which were spread to grass under ambient conditions, *E. coli* O157 levels decreased by four or five orders of magnitude after 50 days. *E. coli* O157 levels in the samples stored in plastic boxes took 99 days to decrease by the same amount.

Kudva *et al*. (1998) reported that *E. coli* O157 survived for at least 47 days in outdoor cattle manure heaps aerated by turning. In heaps that were not aerated, but seeded with cultures of *E. coli* O157, the temperature strongly influenced the viability of the bacteria. At -20^{o}C and 4^{o}C there was an initial c. 2 log decrease in bacterial load after 48 hours. However, at these temperatures the levels of pathogen did not decrease

further for the next 98 days. As with the previous studies, increased rates of bacterial kill were observed at higher temperatures (23, 45 and 70^{o}C).

Soil cores, cattle manures and river water were all assessed for their abilities to support dosed cultures of VTEC in laboratory scale experiments (Maule 1996). *E. coli* O157 survived best in soil cores from a grass lawn, where a reduction from 8.1×10^{7} to 8.7×10^{6} cells/g sample occurred after 63 days at 18°C. In cattle faeces, *E. coli* O157:H7 numbers were reduced from 7.1×10^{5} to 3.5×10^{5} cells/g sample after 54 days at 18°C. River water and cattle slurry contained no viable *E. coli* O157 after 13 days and 9 days, respectively, at 18°C. It is likely that the short survival time of *E. coli* O157 in slurry was a consequence of constantly shaking the sample, thereby ensuring high levels of aeration. This hypothesis is supported by Mawdsley *et al*. (1995) who reviewed a number of earlier studies and concluded that survival times for (non-toxigenic) *E. coli* in soil were significantly lower than in slurry.

Wang *et al*. (1996) studied the relationship between temperature, pH and *E. coli* O157 survival in cattle faeces. Changes in faeces pH occurred over time as a function of both the bacterial load and the storage temperature. Storage at 22^{o}C, resulted in an initial 100-fold increase in bacterial load over the first week of storage. Over the same time period, the pH of the faeces increased from pH 7.1 to pH 8.0. Conversely, low temperature storage (5^{o}C) caused a slow drop in pH to around 6.5 over two months. Research on the impact of pH food preservation treatments indicated that *E. coli* O157 was extremely pH tolerant (Benito *et al*. 1999, Glass *et al*. 1992). Moreover, Gordon and Small (1993) reported that unusual hardiness to low pH contributes to *E. coli* O157 pathogenicity by allowing the bacteria to survive passage through the human stomach.

A recent US study investigated the survival of *E. coli* O157 labelled with a plasmid encoding a jellyfish fluorescent green protein in cattle manures and slurries stored at different temperatures (Himathongkham *et al*. 1999). As in previous studies, a strong positive correlation was found between high temperature and a decline in *E. coli* O157 viability in both slurry and solid manure. The study also attempted to account for pathogen position and local changes in pH, moisture content, redox potential (a

measure of oxygenation) and ammonia in different areas of manure heaps over 60 days of storage (Table 3). Increased bacterial numbers for the first three days at both 37^{o}C and 20^{o}C were observed, before a temperature- and location- dependant decrease in survival of *E. coli* O157. If the initial rises in *E. coli* O157 numbers are ignored, the pathogen decline rates fitted well to those expected for a first order reaction over the 60 days the wastes were studied. Assuming that first-order kinetics apply after 60 days, then these data allow, for the first time, accurate predictions to be made of the decline of *E. coli* O157 in cattle manures at a range of temperatures.

Table 3. Effect of heap location on *E. coli* O157 destruction rate in cattle manures stored at different temperatures

Storage temp. (°C)	Manure type	Manure heap location	Decimal reduction time* (d)
4	Manure	Top	9.04
4	Manure	Mean middle and bottom	18.59
4	Slurry	ND	21.50
20	Manure	Top	21.60
20	Manure	Mean middle and bottom	13.51
20	Slurry	ND	14.70
37	Manure	Top	8.91
37	Manure	Mean middle and bottom	3.58
37	Slurry	ND	3.10

*Time required to achieve a 1 log reduction in pathogen numbers

Somewhat unexpectedly, Himathongkham *et al* (1999c) found that the inactivation rate was lower for the top layer of manure compared to the middle and bottom layers (except at 4^{o}C). This may be an artefact of holding the manure heaps in plastic bags in incubators, thereby shielding the waste from the drying and sterilising effects of sunlight. The study concluded that microbial inactivation depended on low moisture availability near the surface of manure heaps. However, despite detailed information on the physical changes which occurred in stacked FYM (Table 4), the method of microbial inactivation deep in the heap is still uncertain.

Table 4. Changes in physical properties of cattle manures stored at different temperatures

Temp (°C)	Location inside heap	Ammonia (%)		pH		Moisture (%)		REDOX
		Day 0	Day 60	Day 0	Day 60	Day 0	Day 60	Day 60
4	Top layer	0.02	0.04	7.42	8.84	87.6	79.6	ND
4	Middle layer	0.02	0.02	7.42	7.26	87.6	85.4	<200mV
4	Bottom layer	0.02	0.02	7.42	7.1	87.6	85.8	<200mV
20	Top layer	0.02	0.06	7.42	8.97	87.6	59.3	ND
20	Middle layer	0.02	0.09	7.42	7.39	87.6	86.6	<200mV
20	Bottom layer	0.02	0.10	7.42	7.17	87.6	86.2	<200mV
37	Top layer	0.02	0.07	7.42	9.47	87.6	11.9	ND
37	Middle layer	0.02	0.06	7.42	8.73	87.6	87.6	<200mV
37	Bottom layer	0.02	0.04	7.42	8.54	87.6	88.6	<200mV

2.4.2 *E. coli* O157 in pig manure

Chapman *et al*. (1997) reported that 0.4% of UK pigs cultured positive for *E. coli* O157 in their faeces. Extrapolating from the increasing trend of VTEC prevalence in cattle and sheep in the UK during the 1990s, it is likely that before 1996, VTEC incidence in pigs was even lower, and thus posed little threat to humans.

2.4.3 *E. coli* O157 in poultry manure

Common strains of *E. coli* (causing deep dermatitis in poultry) can be found in high numbers in broiler houses. The condition is more common in well fed, heavy birds, especially when stocking density is high and air quality is poor (Hartung, 1994). Although there is evidence that uncooked poultry may harbour toxigenic coliforms (Samadpour *et al.* 1994) and *E. coli* O157 has been isolated from poultry meat from

some US butchers stores (Beutin 1993), there have been no cases of human verotoxigenesis which have been unequivocally linked with poultry. In the UK, Chapman *et al*. (1997) could find no evidence of *E. coli* O157 in faecal samples taken from 1000 chickens over a 1 year period. However, Heuvelink *et al*. (1999) have reported a VTEC isolation from poultry. A single *E. coli* O157 harbouring a VT2 gene was found in 1 of the 459 pooled turkey manure samples taken from Dutch poultry units. Thus evidence suggests that although the incidence is very low, poultry should be considered a potential source of VTEC.

2.4.4 *E. coli* O157 in sheep manure

E. coli O157 exporting verotoxin has been found in sheep in the UK (Chapman *et al*. 1997) reporting a 2.2% incidence from 1000 sheep sampled at abattoir in NE England. Kudva *et al*. (1996) recorded the first natural isolation of VTEC O157 from sheep in North America whereas Fegan and Desmarchelier (1999) reported that non-O157 toxin-producing *E. coli* were the most prevalent in Australia.

A number of studies have looked at dietary influence on the shedding of both generic *E. coli* (Grau *et al.* 1969) and *E. coli* O157 (Kudva *et al*. 1996) from sheep. Grau *et al*. (1969) showed that well-fed sheep dosed with a non-toxigenic strain of *E. coli* would rapidly remove the organism from their rumen and consequently the dosed *E. coli* could not be cultured from their faeces after two weeks. Fasting resulted in the numbers of *E. coli* increasing in the gut, however when feeding was resumed after fasting, the rumen was rapidly cleared of *E. coli*. Animals fed on high fibre diets and inoculated with verotoxigenic *E. coli* O157:H7 shed the pathogen in their faeces for almost twice as long and at higher levels than those fed on a low fibre diet (Kudva *et al*. 1997). Changing the diet from low to high fibre therefore appeared to increase the rate of cytotoxic *E. coli* shedding.

The concentration of *E. coli* O157 in fresh faeces from inoculated sheep was found to vary between 10^5 and 10^8 cells/g (Kudva *et al*. 1998) and was still viable at concentrations of 10-100 cells/g after extended storage of the waste for 21 months in

nonaerated manure piles. The upper, drier layers of the heap however did not contain viable *E. coli* O157. When an identical manure heap was aerated by frequent turning, the organism disappeared within 4 months. The same study also determined the fate of *E. coli* O157 in spiked sheep manures in laboratory experiments designed to mimic common waste treatments. Numbers decreased rapidly in slurries held at higher (>23^{o}C) temperatures, and the organism was generally not cultured 48 hours after inoculation. However, *E. coli* O157 was still culturable from sheep slurry after 100 days if the slurry was stored below 10^{o}C. Interestingly, the results of the study also showed that the presence of *E. coli* Shiga toxin types 1 and 2 had no influence on the survival of *E. coli* O157 in either sheep manure or slurry.

2.5 Salmonella

Salmonella are Gram-negative facultative anaerobes belonging to the Enterobacteriaceae. The genus comprises a number of human pathogens and arguably, the best known are *Salmonella typhi*, causal agent of typhoid fever, and its closely-related cousins *S. typhimurium*, *S. dublin* and *S. enteriditis* (Jones, 1986). *Salmonella* have been classified into c. 2000 distinct serotypes based on differences in surface and flagellar antigens and infection with *Salmonella* often leads to salmonellosis, a disease that can manifest as gastro-enteritis or more generally as bacteremia or septicaemia. Infected livestock that are colonised by low numbers of *Salmonella* and do not develop salmonellosis, as well as those animals that recover from acute infection, can become asymptomatic carriers of *Salmonella* serving as reservoirs of infection.

Poultry are one of the major reservoirs of *Salmonella*, and there is evidence that the decreasing genetic diversity of breeding flocks is causing a displacement of some serotypes in favour of *S. enteriditis* (Anon 1998d). There are statutory requirements for birds in breeding flocks and hens being reared for egg production (pullets) to be regularly tested for salmonella. Recently most laying hens have started to be vaccinated against *Salmonella enteritidis* before going into lay, in response to pressures from the major retailers rather than any legal requirement.

Salmonella-contaminated animal carcasses are cause for concern because they may be sources of difficult-to-treat antibiotic-resistant *Salmonella* infections in humans. *S. typhimurium* DT 104 is primarily associated with cattle but it has spread to a range of food animals, including pigs, sheep and poultry (Anon, 1998d). Strains of *S. typhimurium* DT 104 tend to have a multi-resistant phenotype to many commonly used antibiotics including ampicillin, chloramphenicol, streptomycin, sulphonamides, and tetracycline.

Salmonellas are best adapted for growth at temperatures around 37°C. They are heat-sensitive and are destroyed at temperatures of 70°C for 2 minutes. However, there is evidence to suggest that *S. typhimurium* DT 104 is more heat-resistant than many

other strains of salmonellae. *Salmonella* have been observed to survive for as long as three years in animal faeces and for as long as nine months in soil where animal manures were applied (Jones 1986).

2.5.1 *Salmonella* in cattle manure

In 1998, a total of 1375 isolations of *Salmonella* from cattle were reported in the UK (Anon, 1998d), representing a considerable reduction in the number of cattle infected compared with the early 1990s. The most commonly isolated serotypes were *S. typhimurium* (49% of all incidences) and *S. dublin* (39% of all incidences). Although there was a definite downward trend in cattle infections, the prevalence of *S. typhimurium* and *S. dublin* have remained high over the last 5 years. The most common type of *S. typhimurium* isolated in the UK was the multiple drug-resistant DT104, representing more than 75% of incidents. A comprehensive investigation by Davies (1997) of 20 farms in England, assessed the prevalence of *S. typhimurium* DT104. Associated with high levels of infected cattle was contamination of grazing land, watercourses, farm vehicles and milking equipment. However, over the course of the study, as hygiene improved in these areas and a number of the dairy herds were vaccinated, infection rates of adult cattle decreased from 89% to 25%, highlighting the advantages of effective standards of cleanliness on farms (Davies 1997)

Jones and Mathews (1975) examined 187 cattle slurries and found *Salmonella* present in 11% of samples, although numbers were exceptionally low, typically less than one organism/g of slurry. The most commonly isolated species were *S. dublin* (60%) and *S. typhimurium* (20%). However, Jones (1976) reported data which showed that heifers exhibiting no clinical signs of Salmonellosis could excrete as many as 10^8 *S. dublin*/g of faeces.

Early studies found that *Salmonella* survival in stored cattle slurry could vary from 11-41 weeks depending on the pathogen species, slurry composition and time of year (Rankin and Taylor 1969; Findlay 1972; Jones 1976; Jones 1980). For example, Jones (1976) concluded that there was little correlation between the range of pH values

observed for slurries (pH 6.5 - 7.5) and the survival of *S. dublin*. Storage temperature had a more pronounced effect on *Salmonella* survival. After 3 weeks, *S. dublin* could not be isolated from *Salmonella* contaminated slurry stored at 30^{o}C, however, for slurry stored at 5^{o}C *Salmonella* could be isolated up to 20 weeks later. Generally, the survival of *S. dublin* increased with increasing slurry solids content, although survival times varied from 13 to 140 days depending on the slurry used and the storage conditions. Provolo *et al* (1999) input data collected from these and other previous experiments into a simple linear regression model, to determine which were the most important variables determining pathogen survival. The analysis revealed that dry matter content had the highest correlation with survival time. On the basis of this relationship they determined that the survival time of *S. dublin* in dilute slurry (1-2% dry matter) was around 70-80 days, whereas it could survive for about 120 days in thicker slurry (7-8% dry matter).

Heinonen-Tanski *et al* (1998) investigated the effects of aeration on the fate of *S. infantis* in cattle slurries stored in farm scale storage tanks, and the effects of temperature in laboratory-scale experiments. In a laboratory scale experiment, increasing the slurry temperature from 4 to 40^{o}C by active aeration of the holding tank led to an increased reduction in *S. infantis* numbers with a reduction from 10^4 to 0.03/g slurry was observed after 21 days. Aeration of large quantities of stored slurry (700 m^3 tanks) caused heat generation, in some cases to 40^{o}C above the ambient temperature of 0^{o}C. This led to reductions of between 99% and 100% in the numbers of *Salmonella* in the slurry after 1 month. The study concluded that aerating slurry provided a rapid method for controlling the numbers of pathogenic *Salmonella* in cattle slurry which was destined for application to land.

PlymForshell and Ekesbo (1996) showed that cattle urine, which was collected free of faecal contaminants, could support viable *Salmonell*a for only 5 days. However, viable *Salmonella dublin* could be isolated from dried faeces from a variety of cattle stall surfaces after almost six years. Further evidence of the resistance of to desiccation was described by Janning *et al*. (1994) who reported that *Salmonella* was the most resistant of the Enterobacteriaceae tested against the drying effects of anhydrous silica

gel. The study revealed that under conditions of desiccation, concentrations of culturable cells of the *Salmonella* serotypes decreased very slowly.

Himathongkham *et al*. (1999) studied the decline of *S. typhimurium* labelled with a plasmid encoding a blue fluorescent protein in cattle manures in plastic bags in incubators. As for *E. coli* O157 (Section 2.4.1), the decline of *S. typhimurium* in waste was a first-order reaction, dependant on both storage temperature and position of the pathogens inside the manure heap(Table 5).

Table 5. Effect of heap location on *S. typhimurium* destruction rates in cattle manure stored at different temperatures

Storage temperature (^{o}C)	Manure type	Manure heap location	Decimal reduction time* (d)
4	Manure	Top	12.70
4	Manure	Mean middle and bottom	20.33
4	Slurry	ND	16.40
20	Manure	Top	24.69
20	Manure	Mean middle and bottom	9.36
20	Slurry	ND	12.69
37	Manure	Top	8.36
37	Manure	Mean middle and bottom	1.73
37	Slurry	ND	2.30

*Time required to achieve a 1 log reduction in pathogen numbers

Salmonella closest to the surface of the heap survived for longer periods than those located towards the centre of the stack, except at 4°C. This may have been a consequence of storing the wastes in plastic bags inside incubators, effectively shielding the surface from natural UV irradiation. Nevertheless, *S. typhimurium* levels declined in a predictable manner and the results of the study make it possible model *S. typhimurium* death during the first 60 days storage in cattle manure. Despite ample data on the local anaerobic environment inside the manure heap (Table 4), little

insight was gained on the mechanism of bacterial death in the centre and lower levels of the manure heap. The study authors speculated that either a lack of nutrients, or waste products generated by dense populations of indigenous microorganisms may have played a role.

2.5.2 *Salmonella* in pig manure

There were 323 isolations reported under the 1989 Zoonoses Order from UK pigs in 1998 (Anon, 1998d) representing an incidence of <0.0001%. Thus *Salmonella* infection in pigs in the UK is currently well controlled. The same cannot be said however for other European countries and in the absence of UK studies, this section of the report summarises relevant research data from these countries.

A comprehensive Finnish study observed that, as was reported for cattle slurry, aeration of pig slurry was important for the rapid decline of viable *Salmonella* (HeinonenTanski *et al*. 1998). This study also found that the slight rise in pH associated with the storage of poultry and cattle wastes was much more pronounced for pig slurry stored in a farm-scale ($62m^3$) tank. Over one month the pH increased by nearly 2.5 pH units, as a result of ammonia formation. The authors speculated that the combination of rising pH and high oxygen levels were sufficient to reduce *Salmonella* numbers, which are adapted to the constant pH and anaerobic conditions of a typical animal gut. Evidence to support this theory includes the fact that temperatures achieved during incubation of the aerated slurry were not high enough to thermally inactivate *Salmonella*. The authors also commented that conditions were suited to the proliferation of predatory protozoa which may prey on bacteria in the slurries, thereby helping to reduce numbers.

When pig slurries were anaerobically fermented, *S. typhimurium* survived several days at 30°C and pH 5, but not at pH 4, indicating the persistence of the pathogen at mesophilic temperatures and extremes of pH (Henry *et al*. 1983).

An investigation of the kinetics of *Salmonella* elimination from mixtures of spent litter and pig excreta during composting reiterated the strong relationship between high temperature and good bacterial kill (Tiquia *et al.* 1998). When piles of excreta and spent litter were turned frequently, temperatures were recorded as reaching 65^{o}C in some parts, and consequently *Salmonella* was eliminated in under 21 days. Ajariyakhajorn *et al.* (1997) also found that storage at 4^{o}C and buffering pH (pH 7.0) led to the longest survival time of 56 days for *S. anatum* in stored pig slurry.

2.5.3 *Salmonella* in poultry manure

Whilst there were 1243 reported *Salmonella* isolations from UK poultry in 1998 (Anon 1998d), there is little UK data describing typical *Salmonella* levels in poultry manures. However, in the US, Kraft *et al* (1969) studied fresh poultry manure from 91 houses and isolated *Salmonella* from 29% of the samples, with levels of <1 to >3×10^{4}/g dry waste.

The survival of *Salmonella typhimurium* in poultry manures has been studied by Himathongkham and Riemann (1999b) and Himathongkham *et al* (1999a). Viable counts of *S. typhimurium* in fresh solid poultry manure stored at 20^{o}C changed little in the first 48 hours. However, prolonged storage for a further six days resulted in a decrease of 1-2 log units. This decrease was accompanied by liberation of ammonia and an increase in pH. The authors concluded that the ammonia found in poultry manure was probably responsible for the rapid decrease in *Salmonella* viability.

Himathongkham *et al* (1999a) also studied the effects of available water (water activity; a_w) on the short-term survival of *Salmonella enteritidis* and *Salmonella typhimurium* in solid poultry manures. The a_w was adjusted by means of saturated salt solutions under defined relative humidities for poultry manure samples which were stored aerobically at 20^{o}C. When a_w was higher than 0.93, a moderate increase in colony-forming units over 8-9 h was found for both strains; for a_w of 0.89-0.75, there was a thousand-fold reduction. Extended storage resulted in a million-fold reduction of *S. enteritidis* in 8 days at an a_w of 0.89. Since both higher and lower levels of a_w,

resulted in markedly lower reductions, the authors concluded that holding poultry manure at an a_w of 0.89 for at least one week would make the manure microbiologically safer for use as a fertiliser. Although sufficient available water is an important consideration when estimating the decline of *Salmonella* in faeces, there is evidence that the drying or desiccation of poultry litter can actually extend *Salmonella* viability (Halbrook *et al*. 1951).

General routes for the dissemination of *Salmonell*a from a deep pit poultry unit have been investigated (Davies and Wray 1994). Although *S. enteritidis* was isolated from wild bird droppings found near the poultry unit, from liquids seeping through the concrete pit wall and from faecal spillage around the pit door, dust and air exhausted from the bird houses contained no pathogens. Wild mice living in and around the manure storage pit were however infected with *S. enteritidis* and were thought to be responsible for the rapid colonisation of birds in a new, poultry house built on the farm.

2.5.4 *Salmonella* in sheep manure

There were 184 reported *Salmonella* isolations from UK sheep in 1998 (Anon 1998d). Current livestock farming practices tend to favour grazing sheep outdoors for the majority of the year. This practice stems largely from a greater risk of infectious disease in housed sheep (Slade and Stubbings 1994) and their ability to graze poor, uneven terrain which seldom has other uses.

Grau *et al*. (1969) investigated the influence of feeding on shedding from sheep inoculated with *S. typhimurium* and *S. anatum*. Salmonellae could not be cultured from the faeces of animals fed with Lucerne chaff 1 week after inoculation. However, animals which had not been fed for 3 days before inoculation, did culture positive for *S. typhimurium* for upwards of 5 weeks. The authors identified no real trends between consistent shedding of Salmonellae from the sheep rumen and feeding or fasting of animals. However, the data suggested a reduction in intestinal numbers may be caused by feeding, and the authors note the importance of this information in sheep due for

slaughter. Similar findings have been reported by (Kudva *et al*. 1997) who demonstrated that fasting of sheep colonised with *E. coli* O157 increased the gut levels of the pathogen.

2.6 Protozoan pathogens in animal manures

The two protozoans which are most commonly associated with diarrhoeal disease in humans are *Giardia* and *Cryptosporidium* (Pell 1997). Although the symptoms of protozoan infection are unpleasant, they are usually self-limiting and cause little long term damage to healthy individuals. As a consequence, until recently, little research was performed on either *Giardia* or *Cryptosporidium*. In 1993 however, there was a outbreak of cryptosporidiosis in Wisconsin, USA which affected over 400,000 people (MacKenzie *et al*. 1994). The outbreak was caused by *Cryptosporidium* oocysts carried in the public water supply, and over the past 5 years research has been undertaken largely to prevent similar outbreaks.

Cryptosporidium infects many animal species, causing symptomatic illnesses mainly in young animals, although older animals may be carriers, and is thought to be readily passed from animals to humans by the faecal-oral route.

The classification of *Cryptosporidium parvum* is currently undergoing rapid changes (Sulaiman *et al*. 1999). There are reports of at least two different genotypes of *C. parvum*, one of which is exclusively isolated from humans, and one of which can be isolated from both humans and cattle. It is uncertain if the human form is the result of a mutation to the cattle form which occurs after human colonisation, or if the two genotypes are truly distinct (Mclauchlin *et al*. 1999). Until the question of different genotypes arose, it was assumed that *Cryptosporidium* infections in humans were zoonotic. This assumption has now been questioned and the clarification of the relative contributions made by the human and bovine forms in human infections requires further study.

Cryptosporidium oocysts can remain viable for about 18 months in a cool damp or wet environment (IFST, 1999). They are quite common in rivers and lakes, especially where there has been sewage or animal contamination. The pathogen has been demonstrated to be susceptible to high concentrations of ammonia at alkaline pH in

laboratory studies (Jenkins *et al*. 1998) and a temperature of 65°C inactivates oocysts in 5-10 minutes (IFST, 1999).

Robertson *et al*. (1992) quantified the survival of various isolates of *C. parvum* oocysts under a range of environmental stresses including freezing, desiccation and processes commonly used for purification of water. Although desiccation and rapid freezing were found to be lethal to *C. parvum*, slow freezing allowed 10% of the cysts tested to retain viability after 52h. The survival of *Cryptosporidium* in human excreta at 4^{o}C was also investigated, and viable cysts were recovered for long periods of time of up to 178 days. Viable *C. parvum* oocysts were preserved by aqueous environments, and could resist a variety of water treatment processes including liming and alum flocculation, if the pH was buffered. *Cryptosporidium* was found to be able to survive for long periods of time in seawater (Robertson *et al*. 1992).

Oocysts are remarkably resistant to many common disinfectants, including chlorine-based compounds. The inherent resistance both to antimicrobial compounds and environmental stress has increased the prevalence of cryptosporidiosis in the UK, which rose nearly 10-fold in cattle and 5-fold in sheep between 1983 and 1994 (Svoboda *et al*. 1997). A later study by Sturdee *et al*. (1998) determined that incidence was high for all tested mammals on a farm located in the English Midlands (Table 6) and finally concluded that *Cryptosporidium* is now ubiquitous amongst mammals in the UK. It appears likely that there is now an irreducible, minimum background level of the organism in UK wildlife and this reservoir would act as a continual source of reinfection of domestic livestock (Sturdee *et al* 1998).

Table 6. Average prevalence of *Cryptosporidium* shedding for mammals on a research estate farm in the UK Midlands.

Animal type	Prevalence (%)
Calves (cattle)	48
House mice	39
Wood mice	39
Bank voles	28
Rats	26
Lambs	19
Ewes	9
Bull (beef cattle)	9
Horses	6
Cows (dairy cattle)	6

Source: Sturdee *et al.* 1998.

2.6.1 *Cryptosporidium* in cattle manure

On cattle farms infected with *C. parvum*, almost all of the calves become infected, resulting in large numbers of oocysts being shed with up to 10^{10} oocysts/animal/day being reported (Anon, 1998e). Sturdee *et al.* (1998) reported a seasonal upsurge in *C. parvum* oocysts shed in autumn and winter coinciding with calving and high *Cryptosporidium* prevalence amongst wild mammal populations.

An estimation of the ability of *C. parvum* oocysts to remain viable (retain an ability to excyst) has been measured using a dye assay. When stored at 4^{o}C in pooled mixtures of calf faeces, 14 % of *C. parvum* oocysts were assessed as still viable after 250 days storage, with over 400 days required for a one order of magnitude reduction in viability (Jenkins *et al*. 1997). There is evidence that a mucopolysaccharide component of faeces may interact with the oocyst cell wall thereby enhancing its resistance to environmental stresses (Robertson *et al*. 1992)

A comprehensive study (Svoboda *et al*. 1997) reported that estimated oocyst viability declined rapidly to 2-3% of initial levels over a three week period in bedding material

left in pens. Storage of bedding in stacked heaps, which reached temperatures of up to 51^{o}C, reduced the oocyst numbers even more rapidly. It was also found that *Cryptosporidium* oocysts in stored FYM and slurries declined rapidly at both 4^{o}C and 15^{o}C, with only a small percentage of oocysts remaining after 3 months. The rate of decline was steeper with higher temperatures and there were no viable spores observed after 4 weeks at 20^{o}C. Furthermore, slurry aeration leading to temperatures of >20^{o}C caused a total kill in less than 24 hours.

2.6.2 *Cryptosporidium* in pig manure

Although there is a little information on protozoan pathogens in UK pig manures, the prevalence of both *Cryptosporidium parvum* and *Giardia* spp. shedding have been quantified in feral pigs in North America (Atwill *et al.* 1997) Shedding was found to be influenced by the age of the animal and by the density of the local pig populations. Piglets less than 8 months old were four times more likely to harbour *Cryptosporidium* oocysts than older animals, a trend similar to that described in young cattle (Anon, 1998e). In addition, members of dense local populations (>2 pigs km^{2}) were found to be 10 times more likely to shed *C. parvum* than animals from less populated areas (<1.9 pigs km^{2}).

2.6.3 *Cryptosporidium* in poultry manures

Cryptosporidium oocysts shed in poultry manures are unlikely to pose as great a hazard to the human food chain as other livestocks. Poultry colonisation is most commonly by *C. baileyi* or *C. meleagridis* which Gregory (1990) reports are unable to infect mammals under normal circumstances.

2.6.4 *Cryptosporidium* in sheep manure

A seasonal rise in *Cryptosporidium* oocyst number during lambing has been reported (Xiao *et al*. 1994), and this post-parturient rise contributed towards the colonisation of new-born lambs. This was demonstrated by the observation that colonised neonate

lambs excreted upwards of 6.5×10^7 viable *Cryptosporidium* oocysts/g faeces in the first 10 days of birth (Svoboda *et al*. 1997). Thus a trend of young animals shedding high levels of *Cryptosporidium* oocysts is apparent in cattle, pigs and sheep.

2.6.5 *Giardia*

Giardia exists as two morphologically distinct forms— the trophozoite, which is an active reproducing form and the cyst, a resistant form associated with prolonged survival. A combination of the difficulty in accurately identifying *Giardia* spp. as well as the relatively mild effects of giardiasis, its susceptibility to both a wide range of antimicrobial chemical and conventional water treatments have all ensured that until recently it was not considered a serious threat to human health. Consequently, there has been little research undertaken on this protozoa, with the majority of effort being directed towards reliable identification, and viability assay methods. Since there is a scarcity of specific information describing *Giardia* infections of livestock, this section of the report collectively discusses what little is known.

There are apparent behavioural and life-cycle differences between *Giardia* and other protozoa including *Cryptosporidium*. In contrast to the strong correlation between shedding of *Cryptosporidium* and both demography and animal age in pigs (Atwill *et al*. 1997), no such relationships were found to exist for the shedding of *Giardia* cysts from pigs (Atwill *et al*. 1997). In contrast however, Buret *et al*. (1990) working in Canada found infection prevalence of 17.7% in sheep and 10.4% in cattle, with higher prevalence in lambs (35.6%) and calves (27.7%). Similar levels (10%) were found in cattle in Colorado, USA in the late 1970s (Davies and Hibler, 1979). *Giardia* has also been reported in cattle in Switzerland (Gasser *et al*. 1987).

Firm evidence that *Giardia* of animal origin can infect humans, was provided by (Buret *et al*. 1990) who were unable to differentiate *Giardia* from human and animal origins by SDS-PAGE and Western blotting (Atwill *et al*. 1997) found that shedding of *Giardia* cysts from infected feral pigs was intermittent, making it essential to sample over extend periods of time for accurate determination of prevalence.

The decline of viable *Giardia intestinalis* (referred to as *Giardia lamblia* in the USA) cysts in mixtures of human septic tank effluent (STE) and pig slurry has been studied (Deng and Cliver 1992). Mixtures of both wastes caused rapid decline in the numbers of viable cysts. The proportion of STE and pig slurry altered the rate of cyst decline, and the report found evidence of a substance in pig slurry that plays an important role in cyst death. As with bacterial pathogens, temperature also had a strong influence on cyst viability. At low temperatures (5^{o}C) a decline in cyst numbers of 10% of the initial value took longer than 150 days. However, at 25^{o}C only four days were for required for a similar effect. A representative time required for a 10% reduction to viable cyst numbers in an even STE:pig slurry mixture at 15^{o}C was one month. *Giardia* cysts are also known to be killed by freezing (Deng and Cliver 1992).

2.7 Viruses in animal manures

As was discussed previously, replication of viral pathogens outwith their usual host range is rare, and thus viral pathogens in animal wastes are unlikely to pose a significant health risk to humans. The single exception to this rule may be a class of viruses termed the rotaviruses which are the causitive agent of scour in calves. The exact relationship between animal and human rotaviruses remains unclear, as does the ability of animal rotaviruses to cause disease in humans. Vesikari (1999) reviews however that a live bovine strain of rotavirus is the basis for an orally-administered human vaccine. Since bovine forms of rotavirus are antigenically similar enough to their human counterparts to be used as a vaccine, the two forms of the virus are closely related and there exists the possibility that bovine rotavirus could infect a human host.

2.8 Summary

Despite the fact that the faeces of common livestock species have been shown to harbour human bacterial and protozoan pathogens, and the potential for transfer of these pathogens into the human food chain, there is a lack of robust data on 'typical' levels in animal manures produced in the UK. The fate of pathogens shed via livestock faeces to the environment has been investigated in a number of studies, although very little of this work relates specifically to UK conditions and there are still large gaps in our knowledge. Nevertheless, some inferences can be drawn on pathogen prevalence and shedding rates, and the factors which affect their subsequent survival and behaviour in the environment.

2.8.1 Levels of pathogens shed by livestock

In many studies, researchers have restricted their analysis to simple presence/absence tests, and in others animals or manures have been inoculated with high levels of the pathogen in order to better study their subsequent behaviour. A summary of the available information on pathogen levels naturally present in manures and faeces is given in Table 7.

Table 7. Reported levels of pathogens in animal manures

Livestock type	Pathogen	Reported levels in manure (CFU or MPN/g)	Comments
Cattle	*Campylobacter*	6.1×10^2 - 2.4×10^8 (Stanley *et al* 1998a)	Beef cattle faeces
		6.9×10^1 (Stanley *et al* 1998a)	Dairy cattle faeces
		3.3×10^4 - 2.4×10^8 (Stanley *et al* 1998a)	Calf faeces
		6.0×10^0 - 3.6×10^2 (Stanley *et al* 1998b)	Stored dairy slurry
	Listeria	—	-
	Salmonella	up to 10^8 (Jones 1976)	Excreta from heifers
		over 1×10^6 (Clinton *et al* 1979)	Cattle faeces
		up to 10^{10} (Jones 1986)	Faeces from infected animals
		up to 10^4 (Kearney *et al* 1993)	Cattle slurry
	E. coli O157	10^2 - 10^5 (Zhao *et al* 1995)	Herds in USA
	Cryptosporidium	2×10^{10} (Svoboda *et al* 1997)	Bedding and calf faeces
		1×10^{10} (Smith 1992)	Animal faeces
	Giardia	—	-
Pigs	*Campylobacter*	—	-
	Listeria	—	-
	Salmonella	—	-
	E. coli O157	—	-
	Cryptosporidium	—	-
	Giardia	—	-
Poultry	*Campylobacter*	6×10^7 (Wallace *et al* 1998)	Turkey litter
		10^4-10^7 (Doyle 1984, Stern *et al* 1988, Prescott and Mosch 1981)	Poultry faeces
	Listeria	—	-
	Salmonella	1×10^7 (Himathongkham *et al* 1999)	Poultry manure
		up to3 x 10^4 (Kraft *et al* 1969)	Dry matter basis
	E. coli O157	—	-
	Cryptosporidium	—	-
	Giardia	—	-
Sheep	*Campylobacter*	up to 1.3×10^5 (Jones *et al* 1999)	Sheep faeces
	Listeria	25 (Fenlon *et al.* 1996)	Sheep faeces
	Salmonella	—	-
	E. coli O157	1×10^8 (Kudva *et al* 1998)	Cattle FYM heaps
	Cryptosporidium	6.5×10^7 (Svoboda *et al* 1997)	Lamb faeces
	Giardia	—	-

There is evidence to suggest that shedding rates of some pathogens are affected by factors including season, breeding and diet. Greater *E. coli* O157 shedding rates were

found in cattle during the summer months (Mechie *et al* 1997), whereas *L. monocytogenes* was most prevalent in cattle faeces in winter (Pell 1997). The birth of lambs led to high levels of *Campylobacter* in sheep faeces (Jones *et al* 1999), and increased numbers of *Cryptosporidium* oocysts (Xiao *et al* 1994). Animal age has been shown to influence shedding rates with heifers shedding more *E. coli* O157 than lactating cows (Mechie *et al* 1997), and a higher prevalence of *Giardia* in lambs and calves than in the adult animals (Buret *et al.* 1990). Shedding of *Cryptosporidium* by feral pigs was greatest for piglets and when the population density was high, although no similar relationship was found for *Giardia* (Atwill *et al* 1997). Dietary factors may also be important, with two studies indicating that fasting calves or sheep prior to inoculation with *E. coli* or *Salmonella* caused shedding rates to increase compared to animals fed normally (Mechie et al. 1997; Grau *et al* 1969). Increasing the fibre content of sheep diets also caused *E. coli* O157 shedding rates to increase (Kudva *et al* 1997).

2.8.2 Factors affecting pathogen survival in manures

Listeria and *Salmonella* levels in poultry faeces have been found to rise immediately following excretion (Himathingkham and Riemann 1999b). Similarly, levels of *E. coli* O157:H5 in seeded cattle faeces were found to rise shortly after inoculation and incubation at 18-22°C (Zhao *et al.* 1995; Maule, 1999; Wang et al 1996; Himathongkham *et al*. 1999c), although this increase in bacterial load only lasted 24 hours. For cattle slurry, higher dry solids concentrations (>5%) have been correlated with increased *Salmonella* survival (Jones 1976; Provolo *et al* 1999). Under most conditions, bacterial populations decline with time, with the rate of reduction depending on the temperature, moisture content, pH, and nutrient or water availability.

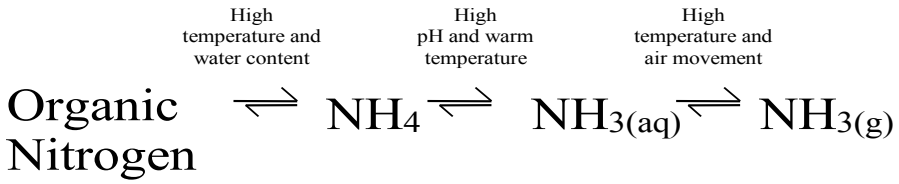
Little specific information exists on the effect of oxygen concentration on the survival of pathogens in manures, however, *Salmonella* and *E. coli* are facultative anaerobes and so will resist oxygen deprivation. *Campylobacter* requires a microaerophilic atmosphere (5-10% O_2; 3-5% CO_2) for growth in a laboratory (Davis *et al*. 1999). Furthermore, *Listeria* is able to survive the anaerobic fermentation used for the

manufacture of silage and is similarly likely to be unaffected by the low oxygen concentrations found in poorly aerated manure heaps and slurries. We were unable find information on the effects of oxygen deprivation on protozoan cysts and oocysts, and thus are unable to make comments for *Cryptosporidium* and *Giardia*.

There was strong evidence from a number of studies using a range of manure types for a positive correlation between temperature and a decline in bacterial and protozoan populations (Jones 1976; Stanley *et al* 1998; Kearney *et al* 1993; Zhao *et al* 1995; Kudva *et al* 1998; Wang *et al* 1996; Svoboda *et al* 1997; Deng and Cliver 1992; Himathongkham *et al*. 1999c). Generally, pathogen viability was reduced at high temperatures (>15^{o}C) and prolonged at low temperatures (around 4^{o}C). In some cases, low temperatures were conducive to slow but sustained increases in the bacterial load of stored manures (Kearney *et al*. 1993). The combined effects of drying and freezing in winter killed *Cryptosporidium* oocysts within a few days (Svoboda *et al* 1997).

Ammonia has known antimicrobial properties (Himathongkham *et al.* 1999c) which play an important role in pathogen decline in livestock wastes. In animal manures, nitrogenous compounds (urea or uric acid) are hydrolysed to dissolved ammonium (NH_4^+) at a rate dependant on temperature and moisture (Figure 1). Mineralisation of organically bound manure N to NH_4^+ also occurs, but at a far slower rate.

Figure 1. Transformations of organic nitrogen in manures



The subsequent conversion of NH_4^+ to dissolved ammonia (NH_3) depends largely on pH, with the percentages of NH_3 in solution at pH 6, 7 ,8, and 9 being approximately 0.1, 1 10 and 50, respectively (Court et al 1964). Most manures have a complex buffering system, although treatment (e.g., aeration) may alter this and thus influence

the pH. Increasing the temperature also increase the proportion of NH_3 in solution at a given pH (Freney *et al*. 1983).

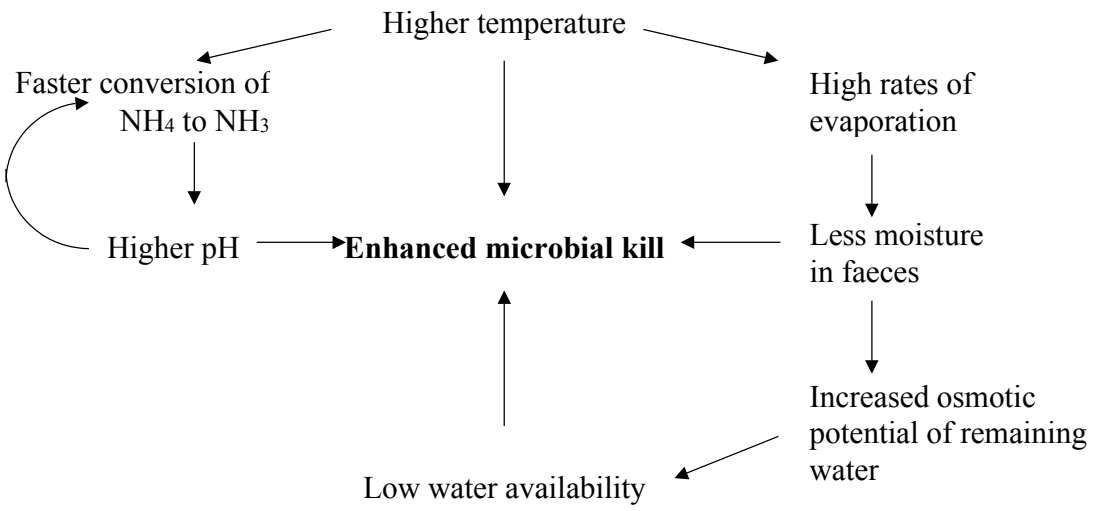
A rise in pH has a strong association with bacterial kill in manures (Turnbull and Snoeyenbos 1973, Wang *et al*. 1996, Himathongkham and Riemann 1999b)) due to the associated increase in levels of dissolved ammonia. *E. coli* O157 has been found to be tolerant of low pH environments (Gordon and Small 1993) and there is some evidence to suggest that a slight lowering of pH may be associated with the proliferation of *E. coli* O157 in cattle manures (Zhao *et al*. 1995, Wang *et al*. 1996, Himathongkham *et al*. 1999).

Gaseous NH_3 can be lost from the manure by volatilisation, a process which depends largely on the rate of transport of air away from the manure surface (ie. the wind speed) or on increased contact with the atmosphere. Thus as the manure dries, the more NH_3 will be lost and the less pronounced any antimicrobial effect due to dissolved NH_3. Furthermore, drying inhibits the natural conversion of nitrogenous compounds to aqueous ammonia in manures (Figure 1). Nevertheless, in dry manures, *Campylobacte*r, *E. Coli*, and *Crypotosporidium* loads decreased more rapidly than in those in moist environments (Jing and Doyle 1998; Hunter and McDonald 1991; Kudva et al 1998; Svoboda *et al* 1997), probably due to the sensitivity of these organisms to desiccation. A notable exception to this was *Salmonella* which was reported to be resistant to the effects of drying (Halbrook *et al* 1951; PlymForshell and Ekesbo 1996; Janning *et al* 1994).

Finally, several studies have suggested that the size or composition of the native microbial population, or the presence of predatory protozoa, may influence pathogen survival rates in manure heaps and soils (Dowe *et al*. 1997; HeinonenTanski *et al*. 1998; Himathongkham *et al*. 1999c). The presence of heavy metals in animal feeds or in soils may also affect microbial population dynamics (Johnson *et al.* 1985)

Although all of the factors described above can contribute to decline of pathogens in manures, frequently an alteration of one of these factors, will cause changes to the others. A diagram outlining these complex interactions is shown in Figure 2.

Figure 2. Schematic representation of the interactions between factors affecting the rate **of** pathogen survival in animal manures.



In summary, the literature review indicates that the factors most likely to influence pathogen survival rates in manures are temperature, moisture content and pH, although certain pathogens may be resistant to changes in one or more of these factors (Table 8).

Table 8. Summary of major factors (where known) that decrease pathogen survival in livestock manures

Pathogen	Temp. >4°C	Freeze/ thaw	pH 8.0 – pH 10.0	pH 3.5 – pH 5.0	Low $[O_2]$	Drying
Campylobacter	✓	—	—	—	—	✓
Listeria	✓	—	×	—	×	—
E. coli O157	✓	—	✓	×	×	✓
Salmonella	✓	—	✓	—	×	×
Cryptosporidium	✓	✓	✓	—	—	✓
Giardia	✓	✓	—	—	—	—

A ✓ denotes a factor that has been shown to decrease pathogen survival; a × denotes a factor that does not influence pathogen survival and an — indicates that insufficient data are available to make comment.

2.9 Pathogen dissemination and survival during manure spreading

Spray drift from aerosols created during the spreading of liquid manures has been widely documented as a route for the dissemination and direct infection of humans and animals by pathogens (Schultze 1943, Evenden 1972, Sorber *et al*. 1976, Shtarkas and Krasil'shehikov 1970, Tamasi 1983). If the mean aerosol particle diameter is <5μm then droplets can be inhaled into human alveoli (Grunnet and Tramsen 1974). A number of studies have concluded that aerosol particle sizes generated by slurry and dirty water spreading are below 5μm (Evenden 1972, Sorber *et al*. 1976, Katzenelson *et al*. 1976)

The first report of long-distance travel of pathogens was by Schultze (1943) who recovered coliforms 230 metres downwind of a sewerage sprinkler which was being used to irrigate crops. Further studies (Evenden 1972), confirmed the earlier findings and subsequent research performed over the next 50 years, using more sensitive experimental approaches observed that travel over further distances is possible with high winds. Sorber et al. (1976) reported that the recovery of coliforms as far as 200m downwind from a sprinkler land-spreading wastewater. Modelling of the experimental data predicted that airborne bacteria would be present above background levels at 500 and 1800m downwind depending on prevailing conditions. Shtarkas and Krasil'shehikov (1970) reported recovery of coliforms 650m downwind from sewage sprinklers spraying farmland when windspeeds varied between 2.6 and 3.3 m/s. One hour after spreading had stopped the numbers of bacteria in the air dropped back to background levels. The authors recommended the introduction of a 1km sanitary zone around farms where wastes are sprayed. Tamasi (1983) recovered microorganisms from nutrient agar plates located 400m downwind of an irrigation system which sprayed liquid manure onto farmland. Windspeed was between 7 and 10 m/s, the relative humidity 44% and temperature 25^{o}C; UV levels were predicted to be high since the weather was clear and sunny.

A more recent study has investigated the effects of various manure spreading technologies, their effects on aerosol formation, and the associated health risks

(Boutin *et al*. 1988). The study investigated the dispersal of bacteria in cattle and pig slurries spread by a raingun applicator, a broadcast spreader with an inclined splash plate, and a generic sprinkler system (Table 9). Windspeeds for the trials were below 2.2 m/s, relative humidity varied between 52 and 70% and solar radiation was low.

Table 9. The effects of different slurry applicators on the distance travelled by coliforms from pig and cattle slurries.

Type of applicator	Distance travelled (m) by coliforms detected using:	
	Anderson sampler	Nutrient agar plates
Raingun spreader	200	350
Sprinkler	90	130
Broadcast spreader	80	120

Boutin *et al* (1988) found no correlation between weather conditions and bacterial dispersal. However, the low windspeeds encountered may not have been high enough to reveal the strong positive correlations with distance for bacterial travel reported by other (Goff *et al*. 1973, Adams and Spendlove 1970). Particles small enough to be inhaled were generated by all of the spreading methods investigated. However, the study concluded that the risks to human health posed by aerosols from slurry spreading were low because people are unlikely to remain for long periods in the vicinity of the spreading machinery, spreading is an infrequent event, and slurry generally contains low numbers of pathogens.

2.10 Survival of pathogens in soil

A variety of human pathogens, including *Campylobacter*, can survive for longer in sterilised surface waters than in untreated water (Thomas *et al*. 1999b). It is widely acknowledged that the difference results mainly from competition for nutrients by the aqueous microflora, although there is some evidence that production of antimicrobial compounds may also play a role (Burgess *et al*. 1999). Almost certainly similar interactions between pathogens applied to soils and the native soil microflora will occur. However, whilst further information describing the exact nature of these interactions is scarce, there is data which describes the effect of soil type, temperature cultivation and other factors. This section of the report summarises our current understanding of pathogen survival in soils.

2.10.1 Survival of *Campylobacter* in soils

Surprisingly for the causative agent of over 60% of gastro-enteritis cases in the UK, there is very little information on *Campylobacter* survival in soils. It is unclear if this lack of information is the result of poor survival of *Campylobacter* in the environment, or a lack of basic research investigating its decline in manures applied to land.

Sturder *et al*. (1999) demonstrated that *Campylobacter* in poultry slurries could be transferred to a sandy soil. Although the study sampled the soil underneath a poultry shed on a weekly basis, no clear conclusions on the survival of *Campylobacter* could be made since the area was continually reinfected with fresh manure.

Stanley *et al* (1998b) reported the fate of *Campylobacter* naturally present in dairy cattle slurries applied to land. Prior to spreading, campylobacters could not be detected in either agricultural land which had been treated previously with slurry or non-agricultural soils. Slurry (containing only a few *Campylobacter*) was applied in June, and 24 hours after spreading, no *Campylobacter* could be isolated from either the dried surface slurry application or from the topsoil underneath, although faecal

coliforms were isolated from both samples. A second trial followed the decline of *Campylobacter* in dairy slurry, which initially contained 128 CFU/g, applied in February to land. Five days after application, the levels in the surface slurry had dropped to 23 CFU/g. A third trial, in March, could detect *Campylobacter* for only 20 days after application. These trials probably represented the most favourable conditions for *Campylobacter* survival, as spreading was in cold conditions with high rates of precipitation.

2.10.2 Survival of *Listeria* in soils

Listeria is ubiquitous in the rhizosphere, and is therefore well adapted to survival in the soil for extended periods of time (Dowe *et al*. 1997, Pell 1997). However, there is evidence that natural incidence is higher in uncultivated soils that have not been disturbed for extended periods of time (Weis and Seelinger 1975, Dowe *et al*. 1997). Dowe *et al* (1997) reported that 8.3% of cultivated and 30.8% of uncultivated soils contained *L. monocytogenes*. Weis and Seelinger (1975) reported similar findings of 12.2% and 44% for cultivated and uncultivated, respectively, although reliable methods for identification of *L. monocytogenes* were not available in the mid 1970s. Dowe *et al* (1997) also studied the effects of soil type, inoculum level and fertiliser on the survival of *L. monocytogenes* in experimental soil columns sampled from a variety of fields growing carrots in Nova Scotia. The data revealed that sandy soil was less likely to harbour *L. monocytogenes* than either a clay or sandy loam, and that partly sterilised soils with low background numbers of native soil bacteria were the most conducive for the survival of *L. monocytogenes*. The study also found that poultry manure applications allowed a higher load of *L. monocytogenes* to be supported compared to soil which had been fertilised with pig slurry or inorganic commercial NPK fertiliser.

There is some disagreement between researchers on the effect of moisture on survival of soil-borne *L. monocytogenes*. Lehnert (1960) reported the survival of Listeria for 730 days in dry soil and 350 days in moist soil, while Welshimer (1960) found that the

survival times of *L. monocytogenes* varied from 69 days in dry soil to 295 days in moist earth.

2.10.3 Survival of *E. coli* O157 in soil

There have been a number of recent studies looking at the differences between *E. coli* O157 survival rates in soils under a range of conditions. The results from such studies not only provide valuable information concerning the survival of *E. coli* O157, but as more data becomes available may eventually allow extrapolation of *E. coli* O157 survival where viability data exists only for less hardy, generic *E. coli*.

There is evidence to suggest that survival times for (non-toxigenic) *E. coli* in soil are significantly lower than in slurry (Mawdseley *et al* 1995), with reported times ranging from 7-8 days (Taylor and Burrows 1971) to a few weeks (Linton and Hinton 1984). However, in the laboratory, dosed cultures of VTEC *E. coli* O157 survived better in cores from a grass lawn, where a reduction from 8.1×10^7 to 8.7×10^6 cells/g sample occurred after 63 days at 18°C, than in cattle faeces or slurry (Maule 1996). In further studies, Maule (1999), found that *E. coli* O157 survived less readily in sieved, grass-free soils compared with intact soil cores containing rooted grass. These authors also found that after 21 days, fewer *E. coli* O157 survived in sieved soils incubated at 37°C (c. 100/g soil) compared with those at 22°C and 4°C (c. 1×10^5/g soil).

Bolton *et al* (1999) showed that when cattle faeces inoculated with *E. coli* O157 was spread to grass under ambient conditions, *E. coli* O157 levels decreased by four or five orders of magnitude after 50 days. *E. coli* O157 levels in the samples stored in plastic boxes took 99 days to decrease by the same amount. *E. coli* released from faeces spread to grass was still detectable in the soil, without culture enrichment, for up to 99 days. A study which examined the survival of generic coliforms in Yorkshire soils concluded that there was a very strong positive relationship between the degree of soil contamination and soil moisture (Hunter and McDonald 1991).

Cattle slurry spiked with *E. coli* O157 was applied to clay and sandy loam soils in Scotland (Fenlon *et al*. 1999) at 50 t/ha, the upper limit specified by current MAFF manure-spreading guidelines. Generic *E. coli* were present at concentrations of 2.2×10^4 and 7.7×10^4/g for the clay and sand, respectively. *E. coli* O157 was present in both samples at 33 cfu /100g. In sandy soils, *E. coli* O157 was isolated from surface grass, and water and soils at depths of 0-2.5, 2.5-5.0 and 5.0-20 cm, 24h after slurry application. However, the toxigenic coliforms were not detected at any depth on subsequent samplings, and in less than 6 weeks total *E. coli* levels had fallen to pre-slurry application levels. In the clay soil, *E. coli* O157 was not detected in any drainage water samples, however it was detected for 20 and 13 days in the surface 2 cm of soil and on grass, respectively. For the clay loam, it took two months for total *E. coli* numbers to return to pre-application levels. These data outline the differences between drainage of different soil types and the effect that this has on movement of pathogens. Pathogenic *E. coli* O157 were unable to move into the poorly-drained clay soil matrix, and thus were isolated for extended periods from the upper surfaces of the clay loam. Conversely, well drained sandy soils allowed greater movement of the *E. coli* through the soil matrix, thereby spreading the bacteria through a greater volume of soil. Thus, total bacteria numbers declined below detection limits more rapidly in sandy than in clay soil. This study provided some evidence that clay soils may bind VTEC, but further study is required before firm statements to this effect can be made.

Concerns were raised in the US about the implications of poultry manure disposal when the production of birds doubled between 1991 and 1995. This large increase prompted research to investigate generic (non-VTEC) faecal coliform transport through soils fertilised by poultry (McMurry et al 1998). In all the soils studied, faecal coliforms were released from the manures and followed the drainage of simulated rainfall over 36 hours. Viable *E. coli* numbers collected from the drained water ranged between 2×10^5 and 3×10^6 /ml. The authors concluded that although groundwater contamination by faecal coliforms could be significant during even modest rainfall, tilling the soil prior to manure application slowed coliform movement.

2.10.4 Survival of *Salmonella* in soils

Salmonella have been shown to survive for long periods (up to 968 days) in soils (Jones 1986). Survival times of up to 300 days in soils spread with cattle slurry have been found, with survival for up to 259 days reported for soils amended with animal faeces (Jones 1986). Factors affecting survival in soil were also reviewed by Jones (1986) and included initial number of organisms, temperature, frost, moisture content, humidity, sunlight, salt concentration, soil texture, organic matter content and presence of other micro-organisms. The author concluded that the large variation in survival times was not surprising given the large number of factors affecting survival.

Although *Salmonella* can survive for extended periods in soils, where actual numbers present were determined it was shown that levels decline rapidly. Typically, soils seeded with *Salmonella*-contaminated manures rarely cultured $>10^2$/g of soil two weeks after application (Jones 1986). More recent results (Turpin *et al* 1993) indicate that *Salmonella* may persist in soils for even longer periods in a viable but non-culturable state, thus they would not be detected using traditional techniques.

2.10.5 Survival of protozoans in soil

Little is known on how *Cryptosporidium* viability is affected by a soil environment. However, an experiment designed to assess the effects of drying and temperature on *Cryptosporidium* oocysts placed in semi-permeable membranes on pastures showed that the oocysts were susceptible to drying (Svboda *et al*. 1997). Estimated viability declined to undetectable levels after 2-4 weeks in summer, whilst in winter the combined effects of drying and freezing temperatures appeared to kill oocysts rapidly after only a few days. This study also found that up to 90% of oocysts applied to soil in excreta could be recovered in the soil. Viable oocysts could then be leached from the soil matrix for extended periods of at least 3 months.

Similarly, the survival of *Giardia* in soil is an area which requires further study before comments can be made. However, frosts may reduce the viability of *Giardia* cysts since they are known to be killed by freezing (Deng and Cliver 1992).

2.10.6 Factors influencing pathogen movement through soil

When manures are applied to land there is likely to be some movement of any pathogens they contain through the soil matrix, both vertically and horizontally. Clearly the degree of movement will affect the risk of pathogens reaching aquifers or surface waters. If these waters are subsequently used for irrigation or livestock drinking there are obvious implications for food safety. Factors affecting the movement of pathogens through and across soil have been comprehensively reviewed by Mawdsley *et al* (1995) and are summarised in Table 10.

Table 10. Factors known to influence the movement of pathogens through and across soils

Movement type	
Horizontal	Vertical
Soil type	
Soil water content	
Rainfall/intensity of rainfall	Rainfall/intensity of rainfall
Temperature	Proximity of pollutant source
Mesofaunal activity	Agricultural practice
Surface charge and size micro-organism	Weather/season of application
Presence of plant roots	
Soil pH	

Generally, pathogen survival is favoured in aqueous environments and thus water availability and movement are the single most important factors in determining how far pathogens are likely to move through or across soils. Although temperature is also an important consideration, with higher temperatures lowering pathogen survival, soil temperatures below the top 5 cm fluctuate seasonally, and are largely unaffected by daily temperature differences. Thus temperature and season are the second most

important considerations for estimating pathogen dissemination. Mean soil temperatures in the UK seldom exceed 15^{o}C at a 10 cm depth whereas average winter temperatures are around 5^{o}C (Mawdsley 1995). Other considerations aside, at 5^{o}C, in an environment with adequate water, the majority of the pathogens discussed by this report would be expected to survive for several months.

2.11 Pathogen survival on vegetation

A number of studies have found that pathogens applied directly to plants survived for shorter periods of time than those applied to soils (Jones 1986). Beutin (1996) reported that *Listeria monocytogenes* was widely distributed on plant vegetation, especially raw vegetables and speculated its presence on crop surfaces was likely to be due to contamination from decaying vegetation; animal faeces, soil; surface, river and canal waters, or effluent from sewage treatment operations. Beutin (1996) also cited evidence that *Listeria* could survive in plant materials for as long as 12 years. Other authors however have been unable to find any evidence of *Listeria* on herbage (Behrendt *et al*. 1997, Gras *et al*. 1994). Behrendt *et al* (1997) were unable to isolate *Listeria* from a variety of grass pastures, over various seasons, and Gras *et al*. (1994) were unable to isolate the pathogen from the more sheltered, highly folded, leaves of 89 lettuces sampled.

There are few specific data describing the fate of VTEC in manures applied to grazing pastures, although studies have demonstrated that *E. coli* O157 was able to survive for longer than 3 weeks on a variety of human food crops including salad vegetables (Abdul-Raouf *et al*. 1993), iceberg lettuce (Diaz and Hotchkiss 1996) and watermelons (Delrosario and Beuchat 1995). Furthermore, *E. coli* O157 was able not only to survive, but proliferated both on stored apples and in the acid environment of preserved apple juices (Fisher and Golden 1998)

Jones (1986) showed that *Salmonella* survived in small numbers for between 2 and 36 weeks in slurries which dried on pasture, which may present some risk of cross infection. He concluded that the risk of infection from livestock grazing pastures fertilised with manures containing *Salmonella* was low, as animals fed from pastures experimentally-seeded with *Salmonella* were not easily infected. However, *Salmonella* was recoverable from grass fertilised with 10^7 CFU/g sewage sludge for almost 72 weeks, although it is very unlikely that such levels would ever be applied to pasture in practice..

Limited information exists on the fate of *Campylobacter* on herbage. Generally however, *Campylobacter* does not appear well adapted for long term survival in non-aqueous environments (Solomon and Hoover 1999).

2.12 Pathogens in sewage sludge

2.12.1 Introduction

Human sewage sludge contains a number of human pathogens which may present a health risk when sludge is spread on agricultural land. However, the potential transmission of pathogens is minimised by sludge treatment and restrictions on application practices and land use.

Because the risks of pathogens transfer from human sludge are often perceived to be greater than those from animal manures, there has been a substantial body of work investigating the fate of sludge pathogens both during treatment and after land spreading. Sludge and animal manures are both organic materials, similar in composition in many respects, and information from sludge pathogen research may be useful in assessing the behaviour of manure pathogens.

2.12.2 Effectiveness of sludge treatment

The Code of Practice for Sewage Sludge Use in Agriculture (DoE, 1989) lists examples of what are considered to be effective sludge treatment processes. Mesophilic anaerobic digestion (MAD) is the treatment method currently most widely used by the industry in the UK. To be effective the mean retention time should be at least 12 days at 35°C or 20 days at 25°C, followed by retention at a secondary stage for at least 14 days. The method has been found to significantly reduce levels of some pathogens (including *Giardia* and *Cryptosporidium*), but does not completely eliminate them (Smith, 1996).

Composting is effective in eliminating sludge pathogens providing that temperatures of 55-60°C are reached for 3 consecutive days. Windrow turning presents some problems as the surface layers do not always reach these temperatures and are a potential source of reinfection. Lime treatments, where slaked lime (calcium

hydroxide) is added to the sludge to raise the pH to 10.5-11.5, are effective against most bacteria including salmonellas. Pasteurisation and thermal drying ,which involve heating sludge to 70-100°C, are very effective in destroying pathogenic organisms. However, none of these treatments is widely used at present in the UK.

2.12.3 Survival of sludge pathogens in soil and vegetation

The survival of sludge pathogens in soil and vegetation has been comprehensively reviewed by Smith (1996) and Sorber and Moore (1987), who found that temperature was the most important factor influencing pathogen survival in sludge-amended soils, with increasing survival time a function of decreasing temperature.

Coker (1983) found that sludge borne bacteria also declined rapidly on exposure to light, desiccation and antagonism when applied to soil. The survival of *Salmonella* was found to decrease on well drained and dry soils, compared to saturated soils (Pike and Carrington, 1986). These authors also found that light, infrequent applications of sludge were more effective for *Salmonella* destruction compared with heavy, infrequent dressings. Experiments where sludge was inoculated with *Salmonella* found that 45 days was required for a 99% reduction and persistence times were over 5 months (Sorber and Moore, 1987). However at more typical levels of *Salmonella* in sludge, a 90% reduction in numbers was obtained after 3 weeks (Pike and Carrington, 1986), and Citterio and Frasinetti (1989) could not detect *S. typhimurium* 2-3 weeks after application. Interestingly, Turpin *et al*. (1992) reported that sludge applications promoted the antagonistic effects of soil microorganisms increasing rate of *Salmonella* die off in soil. Rudolphs et al (1951) detected no *Salmonella* 7 days after it was sprayed onto vegetation.

Faecal coliforms in sludge are inactivated quickly in soil and vegetation. For liquid sludges, Braids (1970) reported that 99% were killed after 30 days, and Bell and Boyle (1978) cited 99.9% mortality after 35 days. Where dried sludge was applied, destruction was achieved in 12 days. Sorber and Moore (1987) estimated that <6 weeks was required for complete destruction of faecal coliforms in soil. Similarly,

Bell and Boyle (1978) showed that 90% of coliforms applied to vegetation in sludge were inactivated within 48 hours, and none were detected after 14 days.

Kowal (1982) concluded that survival times for sludge borne protozoa in soil were 2-10 days, and other authors have reported that the cysts were very sensitive to desiccation (Coker, 1983, Sorver and Moore, 1987).

2.13 Novel survival mechanisms employed by human pathogenic microorganisms

2.13.1 The viable-but-nonculturable state

In general, in studies that have investigated the survival of human pathogens in animal faeces and contaminated soils, little account has been taken of a dormant state, termed the viable-but-nonculturable (VBNC) state, that some bacterial species have been shown to enter. The VBNC-state has been reported for *E. coli* (Xu *et al*. 1982) *S. enteritidis* (Roszak *et al*. 1984) and *C. jejuni* (Tholozan *et al*. 1999, Stern *et al*. 1994). Pathogens in this state may be important for human pathogenesis as they cannot be detected by standard culture methods. The purpose of the VBNC-state is currently a contentious issue. There are data to support both the contention that it is a degenerative state which signals the start of cellular necrosis, and also that it is a "resting" state with minimal metabolic activity. However, there is compelling evidence that VBNC cells either remain, or can revert to become, pathogenic under favourable environmental conditions (Stern *et al*. 1994). Currently, the study of the VBNC state is in its infancy and practical methodologies for the large scale study of VBNC cells have not been developed sufficiently for routine diagnostic use. Therefore it is not possible to determine if the localised environment inside manures is conducive for pathogens to enter a VBNC state and it is not feasible to make realistic assessments for any role VNBC may play for survival of pathogens in animal wastes.

2.13.2 Intra-protozoal growth

Intra-protozoal (IP) growth of bacterial pathogens has also been largely overlooked as a vector for increasing survival of pathogens in faeces and contaminated soils. IP growth has been associated with increased environmental survival, virulence, and resistance to antimicrobial agents for a number of human pathogens including *Legionella* (Fields 1996), *Mycobacterium* (Steinert *et al*. 1998), and *E. coli* O157 (Barker *et al*. 1999). It is possible that amoebic tropozoites harbouring pathogenic bacteria, ingested by grazing cattle may play a role in the transmission of pathogens in herds. However, although the presence of predatory protozoa in sewage and soils is

widely acknowledged, any comments concerning the contribution that is made to dissemination of pathogens by this novel protective niche would be highly speculative at present.

3. CURRENT MANURE MANAGEMENT PRACTICES

3.1 Introduction

The purpose of this section of the report is to review current on-farm livestock production and manure management systems in England and Wales.

Most animal houses provide an attractive environment for microorganisms. The atmosphere is warm and moist and the supply of nutrients in the form of animal feed, bedding and excreta is rich, colonisation sites are plentiful and natural disinfectants such as UV radiation are absent. Methods of cleaning and disinfecting livestock housing are well established, though the practical implementation may be tiresome and not all the recommendations may be followed in practice. Meticulous care is required to disinfect all surfaces to a satisfactory standard and they will quickly become recontaminated as reservoirs of some microorganisms are inevitable.

Following removal from animal housing, manures are commonly stored before being land spread. Liquid manures (slurry) and solid manures (straw based FYM and poultry manure) are handled, stored and treated very differently, and this will have a major impact on the levels and survival of microorganisms in these materials. Similarly, manures are spread throughout the year to a range of cropping situations using different equipment and contrasting soil incorporation strategies.

The research reviewed in Section 2 showed that a number of factors affect the survival of pathogens in stored animal manures including temperature, storage time, pH, manure dry matter content and aeration. This section details current manure production, storage and land spreading practices, to allow information on the occurrence and survival of pathogens in manures described in Section 2 to be used to assess the effectiveness of current manure management practices in controlling the survival and spread of pathogens into the human food chain.

3.2 Manure production and use in England and Wales

Recent estimates show that in 1997 approximately 68 million tonnes of manure were produced by housed livestock in England and Wales (Pain, 1998). Of this, about 77% was from cattle, 15% from pigs, 6% from poultry and 2% from sheep (Table 11).

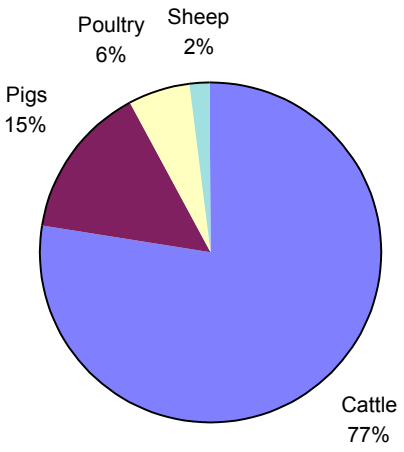
Most of this manure is recycled to agricultural land as it is a valuable source of plant nutrients (NPK and S) and organic matter. In this way, the farmer can reduce the requirement for inorganic fertilisers thus saving input costs, and can help to maintain the quality and fertility of his soil.

Table 11. Quantity of manure (slurry and FYM) produced by housed livestock in England and Wales in 1997.

Livestock type	Slurry (Mt)	FYM (Mt)	Total manure (Mt)
Dairy cattle	15.5	10.4	25.9
Beef cattle	9.2	17.2	26.4
Sheep	0	1.3	1.3
Pigs	3.3	6.7	10.0
Poultry	0	3.9	3.9
Total	*28.0*	*39.5*	*67.5*

Source: (Pain, 1998)

Figure 3. Percentage contribution by animal class to the total manure produced by housed livestock in England and Wales in 1997



3.3 Livestock production systems

3.3.1 Cattle

In 1997, there were c.7.8 million cattle in England and Wales (Table 12), producing an estimated 52 million tonnes of manure annually (Pain *et al*. 1998), of which 25 Mt was handled as slurry and 28 Mt as straw-based farmyard manure (FYM).

Table 12. Quantities of slurry and FYM produced by cattle in England and Wales in 1997.

Cattle type	Number (thousands)	Total slurry produced (Mt)	Total FYM produced (Mt)
Dairy cattle	2462	15.5	10.4
Beef cattle	5361	9.2	17.2
Total	*7823*	*24.7*	*27.6*

Source: Pain *et al*. 1998

3.3.1.1 Beef cattle

Beef cattle reared indoors are generally kept in pens in houses which are naturally ventilated. Animals are usually reared on compound feeds based on cereals, grass silage or maize silage. Animals of widely varying ages are not usually housed in the same air space to prevent disease transmission (Hardy & Meadowcroft, 1986). The houses are commonly fully bedded with straw (FYM based systems) or less often have slatted floors (slurry based systems).

3.3.1.1.1 FYM based systems

Fully bedded systems require high rates of straw usage, with one estimate indicating that straw use on silage based diets is around 1 t per head over a twelve month cycle, compared with 0.7 t per head on cereal based diets (Hardy & Meadowcroft, 1986). Normally fresh straw is added as the bedding becomes soiled, so the layer of manure gradually increases in depth. Stocking density is usually 4.0-5.5 m^2 per animal. Results from the Manure Management Practices Survey of the Beef Industry (ADAS, 1998a) suggested that these areas are cleaned out once a year by 19% of farmers, twice a year by 39% of farmers and three times a year or more by 42% of farmers.

Part-bedded systems reduce the requirements for straw by up to 50% by providing bedded areas in only part of the house, with a scraped area behind feed troughs where cattle can defecate and urinate. Scraped areas are generally cleared weekly or twice weekly, but a system for collecting the slurry must be available. Sloped floor systems can be used where bedding materials are scarce or expensive, and are more suitable for cattle on a high dry matter diet. In these houses, the floor slopes from the feed trough towards the rear of the pen. The higher part of the pen remains dry and the lower part can be mucked out daily with a tractor and scraper.

3.3.1.1.2 Slurry based systems

These systems are sometimes used for animals on a low dry matter diet such as silage, the trend in the beef cattle industry however is away from slatted floors and slurry systems. Stocking density is usually 1.5 - 2.5 m^2 per animal (Lawrence, 1994). Cattle are housed in buildings with slatted floors, where slurry collects in a pit up to 2m deep beneath the floor. There is usually enough capacity in the pit for 10-15 weeks of slurry production.

3.3.1.1.3 Grazing beef cattle

Beef cattle generally graze outside for around 180 days a year (during late spring, summer and early autumn), although the proportion of time spent outdoors depends on soil conditions and weather patterns. Many areas of grass are grazed non-systematically and extensively, although a number of the more successful farmers are adopting grazing strategies similar to those used for dairy systems (section 3.3.1.2.5). There are some 'zero graze' systems where the animals are permanently housed. During grazing, faeces and urine will be deposited directly onto the sward surface and will remain there until it breaks down and becomes incorporated into the soil.

3.3.1.2 Dairy cattle

Over the past 20-30 years there has been a decline in the number of dairy units and an increase in the number of cows kept on each unit (Blowey, 1994). The majority of herds are housed from October to March (180 days), but on heavier, poorly drained soils the housing period may be extended up to 240 days. Temperatures are not controlled in the housing, although adequate ventilation is important to reduce the risk of disease.

3.3.1.2.1 Cowsheds

In some small herds (<40 cows), cows are tethered in partitioned areas and stand or lie on a floor raised above a dunging passage. Straw is usually used as bedding, although other materials such as bracken or sand can also be used. Cows are fed and milked in their standing areas and may be released into a loafing area once a day for cleaning out. Straw left in place for long periods may become compacted and produce a dirty lying area.

3.3.1.2.2 Cubicles

Cubicle systems are similar to cowsheds, but cows are not tethered and can choose to lie in their individual cubicle or stand in the dung channel, loafing or feeding areas. Most loafing and feeding areas are now covered as this reduces the dilution by rainfall and therefore the volume of slurry produced. The dunging passages are usually scraped twice daily during milking (Blowey, 1994), which reduces indirect faecal contamination of the cubicles via cattle feet.

Straw is provided in the cubicles with a requirement of 120 kg per cow for 180 days being quoted in the MAFF Water Code (MAFF, 1998) and 350-450 kg per cow over a 30-week winter period estimated by Blowey (1994). Chopped straw usually compacts into a mat and is less likely to be pulled out of the cubicle, hence producing fewer problems for the slurry handling systems. Dung pats and soiled bedding are usually removed from the cubicles just before scraping (twice a day) and fresh bedding provided daily.

Woodshavings, sand, shredded paper and sawdust have all been used as bedding materials, although sand may run into and eventually block slurry handling systems. Shredded paper is absorbent, but can become compacted when wet. Proprietary mats are also available but must be kept dry, as wet mats support bacterial growth (Blowey, 1994).

3.3.1.2.3 Loose yards

Dairy cows may be kept in loose yards, where straw is used as a bedding material. The yards may be separated into bedded areas for lying and non bedded areas for feeding, loafing and dunging. Straw requirements are quoted in the MAFF Water Code as 530 kg/cow over a 180 day housing period, but depend on the length of the housing period, straw quality and stocking density.

Cows are usually allowed to come back to a freshly bedded yard after morning milking. The frequency of cleaning out varies, with opinions on the ideal frequency

varying between at least once over winter to every two weeks (Blowey, 1994). Results from the Manure Management Practices Survey of the Dairy Industry (ADAS, 1998b) found that straw-bedded areas are cleaned out once a year by 13% of farmers, twice a year by 24% of farmers and three times a year or more by 63% of farmers. Where a standing area is provided this is usually scraped twice daily to reduce straw use.

3.3.1.2.4 Other facilities

Every dairy farm will have a few well-bedded pens where sick or parturient cows can be housed. These should have deep straw and be easily cleaned. Calves may be kept in pens or loose boxes either individually or in small groups. They are generally kept on straw bedding which is cleaned out regularly. Most farms will have a concrete collecting yard where cows stand prior to and after milking. This area is usually uncovered and will be used in both summer (when cows are brought in from pasture) and winter; it is normally scraped clean at least once a day.

3.3.1.2.5 Grazing dairy cattle

Most dairy cattle will graze outside from April to September (180 days), although the proportion of time spent outdoors will depend on soil conditions and weather patterns.

There are several different grazing systems used on dairy farms including:

Two sward system. One area is regularly cut for silage and the other regularly grazed

Set-stocking. Stock graze a fixed area for a long period, usually at low stocking rates.

Continuous grazing. A large area is grazed for 2-3 months, usually at high stocking rates.

Three field system. Alternate areas are used throughout the season for silage or grazing.

Block grazing. Grass areas are split into large blocks and grazed on rotational basis.

Paddock grazing. A formal method of rotational grazing using 20-30 small paddocks.

Strip grazing. A fresh strip of herbage is provided twice daily using moveable fences.

Zero grazing. Animals are permanently housed and fed grass as silage

Whilst the animals graze, their faeces and urine will be deposited directly onto the sward surface and will remain there until it breaks down and becomes incorporated into the soil.

3.3.1.3 Slurry and FYM analysis

Manure dry matter contents and chemical analysis will be affected by housing conditions, diet, straw quality and depth, stocking density, animal health, dilution with washings and length of storage. Typical analyses for cattle slurry and FYM are shown in Table 13. Slurry may also contain quantities of straw or other bedding material as well as excreta. Both slurry and FYM may contain grit, waste feed, milk, other secretions, and traces of veterinary and cleaning products.

Table 13. Selected properties of cattle slurry and FYM

Manure type	Dry matter (%)	Total N (kg/t fw)	Ammonium-N (kg/t fw)	pH
Beef slurry	10	3.4	1.4	6.4-8.1
Beef slurry	6	2.3	1.2	6.4-8.1
Beef slurry	3	1.3	0.8	6.4-8.1
Dairy slurry	10	4.1	1.7	6.6-8.3
Dairy slurry	6	3.0	1.5	6.6-8.3
Dairy slurry	3	2.0	1.1	6.6-8.3
Cattle FYM (fresh)	25	6.0	1.5	ND
Cattle FYM (old)*	25	6.0	0.6	ND

*Stored for longer than 6 months
ND = No data
Source : MAFF (1994); Chambers *et al* (1999); pH data from ADAS manure database

3.3.2 Pigs

In 1997, government statistics indicated that the pig herd in England and Wales was around 6.7 million animals (Table 14). Around 10 Mt of pig manure is produced annually (Pain *et al,* 1998), of which 3.3 Mt is handled as slurry and 6.7 Mt as straw-based FYM.

Table 14. Quantities of handled slurry and FYM produced by the pig herd in England and Wales in 1997.

Pig type	Number (thousands)	Total slurry produced (Mt)	Total FYM produced (Mt)*
Breeding sows	771	0.77	1.78
Boars	37	0.00	0.13
Fatteners >110 kg	56	0.04	0.08
Fatteners 20-110 kg	4088	2.11	4.31
Fatteners <20 kg	1779	0.38	0.42
Outdoor pigs	376	N/A	N/A
Total	*6730*	*3.30*	*6.73*

Source: Pain *et al*. 1998
N/A= not applicable

3.3.2.1 Production systems

With the exception of the west of England, where straw availability is limited, most pig holdings still have both slurry and FYM production systems. The majority of farms (86%) use dry feed, with 11% on liquid feed and 3% on whey or swill (ADAS, 1997a). The use of liquid feeds may increase in future as farmers try to decrease production costs.

3.3.2.1.1 Slurry based systems

Fattening pigs (sometimes referred to as growing or finishing pigs, generally 20-90 kg bodyweight) may be raised in slatted slurry based housing systems, where the pigs are kept together in pens of about 10-20 animals. Usually temperature, ventilation and lighting levels are controlled in the houses, although this is not always the case. The most popular housing is where slurry drops through slatted flooring into a pit beneath the house, which has 4-8 weeks storage capacity.

The Survey of Manure Management Practices in the Pig Industry (ADAS, 1997a) found that 24% of respondents removed slurry from the main houses daily, 25% weekly, 47% monthly and 4% only twice a year. When slatted houses are cleaned out the washing water will also be collected in the slurry pit diluting any stored slurry.

3.3.2.1.2 Straw based systems

Fattening pigs and sows raised indoors may be kept on straw-based bedding systems. Animals are kept together in pens of about 10-20 animals, usually in naturally ventilated barns where temperature control is less effective than in slurry based systems. Generally straw is added at the rate of 102 kg/animal/year (MAFF, 1998b).

The Survey of Manure Management Practices (ADAS, 1997a) found that 56% of respondents removed FYM from the main houses daily, 24% weekly, 15% monthly and 5% twice a year or less. When houses are washed down the washings will normally be collected in the farm dirty water system.

3.3.2.1.3 Outdoor pig farming

Currently 29% of sows and c.8% of fatteners are managed in outdoor systems, usually on free draining soils. Pigs are kept in groups of 10-20 animals and are free to roam within fenced areas. They are provided with food, water, a shelter containing straw

bedding and sometimes wallows. Land for outdoor pig farming tends to be used as part of the normal farm rotation, and pigs will often be put onto a cereal stubble in the autumn (September) and remain in the field for one to two years. The crop sown following outdoor pigs will depend on the farm rotation but is likely to be a cereal, although potatoes and other vegetable crops may also be grown.

3.3.2.2 Slurry and FYM analysis

Manure analysis is affected by housing conditions, diet, straw quality and depth, stocking density, animal health and length of storage. Typical analyses are given in Table 15.

Table 15. Selected properties of pig slurry and FYM

Manure type	Dry matter (%)	Total N (kg/t fresh weight)[1]	Ammonium-N (kg/t fresh weight)[1]	pH[2]
Pig slurry	10	6.9	3.0	6.6-8.8
Pig slurry	6	5.1	2.8	6.6-8.8
Pig slurry	3	3.4	2.1	6.6-8.8
Pig FYM (fresh)	25	7.0	1.8	ND
Pig FYM (old)*	25	7.0	0.7	ND

[1]Chambers *et al* (1999); [2]ADAS manure database
*Stored for longer than 6 months
ND = no data

Note: pig slurry can range from a semi-solid substance at about 12% dry matter to a liquid with 2% or less dry matter depending on the production system and extent of dilution from drinker leakage or from rainwater during storage. It may also contain small quantities of straw or other bedding material, grit, waste feed, bodily secretions and traces of veterinary and cleaning products.

3.3.3 Poultry

Commercially reared poultry include laying hens (kept for egg production), broilers (reared for meat), turkeys and ducks, and birds in the respective replacement and breeding flocks. This report does not deal with geese or game birds as they comprise a very small proportion of total poultry production.

In 1997, the flock size in England and Wales was around 118 million birds, with an estimated annual output of 3.8 million tonnes of handled manure (Table 16). Of this manure, 32% was from laying hens, 41% from broilers and the remainder from other types of poultry. Currently about 16 % of broiler/turkey litter is burnt as fuel in power stations (Pain *et al*. 1998).

Table 16. Quantity of manure produced by the poultry flock in England and Wales in 1997

Poultry type	Number (millions)	Total manure output (Mt)
Layers	29.4	1.22
Broilers	57.7	1.56
Pullets	9.5	0.16
Other hens	5.7	0.24
Other poultry	16.1	0.67
Total	*118.4*	*3.85*

Source: Pain *et al*. 1998

3.3.3.1 *Laying hens*

Cages. This is the most common production system in England and Wales, with birds kept in cages, stacked several high, in houses where the environmental conditions (temperature, lighting, ventilation) can be controlled. The temperature within laying hen houses is generally maintained at about 21°C. The size of houses can vary from <1000 to 80,000 birds, but at least 450 cm^2 of cage space must be provided per bird.

Birds (pullets) enter the house at age 16 weeks and remain there until they are approximately 72 weeks old. Houses should be thoroughly washed down and disinfected using MAFF approved bactericidal and/or anti-viral agents between crops, and thick deposits of dust removed from all surfaces inside the building.

Manure can be collected and removed from the houses in several ways:

- *Deep pit* - manure falls directly from the cages into an above-ground pit underneath the tiers of cages. The manure is usually only emptied once a year at the end of the laying hen production cycle. Thus, the manure at the time of removal may consist of material which is anything from 1 week to 1 year old. In some deep pit houses, the manure may be treated with pesticides to kill-off fly larvae. If the manure is dry enough, heating may take place in the stack during the storage period.
- *Belt-scraped* - manure falls onto moveable 'belts' installed underneath each row of cages. Recently methods have been developed for air drying of the manure on the belt using ventilated ducts adjacent to the cages on each tier. Manure is removed from the house at different intervals by winding the belts. During summer manure is generally held on the belts for up to a week, during which time some drying can occur; whereas in winter, the belts are normally cleaned at least twice a week. The manure is usually emptied into farm trailers for subsequent removal to a storage area.
- *Stilt house* - similar to a deep pit house, except that the sides of the 'pit' have been removed and the house is effectively raised above the ground on 'stilts'. Manure falls by gravity from the cages and collects in 'open air' heaps underneath the house, with the advantage that manure storage and livestock areas are separated. Drying of the manure is gradual as a result of heating up in the heaps and the drying action of warm air output from the poultry building above, but tends to be greatest in the warmer conditions of spring and summer.

The Survey of Manure Management Practices in the Poultry Industry (ADAS, 1997) found that laying hen manure was removed from houses with caged systems daily by 16% of respondents, weekly by 60% of respondents and at the end of the production system by 25% of respondents.

The majority of laying hens in this country are kept in deep pit or belt scraped houses. The industry is increasingly moving towards belt scraped systems as these provide advantages in terms of reduced odour and ammonia emissions, and better manure handlability. Stilt house systems are not currently in widespread use in this country (Table. 17).

Table. 17 Estimated proportion of laying hens in different cage systems in Britain

System	Proportion (%)
Deep pit - various layouts	71
Stilt house	4
Belt clean without air	18
Belt clean with air	7

Source: Elson, 1998.

Barn/perchery. In a barn or perchery system, birds are not restricted to cages and are free to move around the building, where perches are provided at different levels. In percheries, stocking densities are similar to cage systems (maximum 25 birds/m^2), whereas in barn systems they are much less (up to 15 birds per m^2). Manure from the birds falls through slats in the house floor under the perching areas and collects in a pit (see deep pit). Some of the floor area which is not under the perches may be covered with litter (usually sawdust, woodchips or straw). Manure is usually emptied about once a year from the pit.

Deep litter. These systems are effectively a less 'intensive' version of barn systems. As stocking densities are so low (7 birds/m^2), they do not tend to be as economically viable as other systems and are uncommon. Results of the Manure Management Practices Survey in the Poultry Industry (ADAS, 1997b) show that for laying hens on deep litter systems, 68% of producers use woodchips as a bedding material, with straw being the next most popular bedding material (27%), and only small amounts of

shredded paper or proprietary litter used. Laying hens on deep litter were generally given 18 cm of straw, 13 cm of woodchips or 8 cm of shredded paper.

Free range. These systems are similar to barn systems, except that the birds have access to an outside grass area. Most manure (70%) is collected in a pit in the house which is usually emptied once a year. The outside area is usually rotated using electric fencing or similar methods, allowing the grass areas time to recover from the trampling of the hens. Sheep or cattle may sometimes graze on land to which free range hens have had access. Recently there has been a move towards smaller, mobile houses rather than permanent buildings for free range hens, although this is not yet a widespread practice.

3.3.3.2 *Broilers and turkeys*

Broilers and turkeys are generally kept on the floor in large houses with between 10,000 and 40,000 birds for broilers and somewhat less for turkeys. Stocking densities based on final bodyweights broilers are 34 kg/m^2 for broilers and 410 cm^2/kg for growing turkeys. Birds enter the house as day old chicks and are removed after about 42 days for broilers and up to 24 weeks for turkeys. Environmental conditions are controlled with temperatures usually at 21°C for broilers and 12-20°C for turkeys depending on the market. The birds are provided with bedding material (litter), which is usually either straw or woodchips, but can sometimes be shredded paper or proprietary litter (e.g. compressed straw pellets). The rate of litter addition is usually 0.5 kg/broiler/crop (MAFF, 1998b) and 4.8 kg/turkey/crop (MAFF, 1994) to a depth of 5 - 10 cm. Soiled litter is removed from houses between each crop, and fresh material provided for the incoming birds. It is recommended that houses are thoroughly washed down and disinfected between crops

Results of the Manure Management Practices Survey in the Poultry Industry (MAFF, 1997b) found that 60% of broiler producers used woodchips as a bedding material, 39% used straw, and shredded paper or proprietary litter were rarely used. Broilers were generally given 9 cm of woodchips, 8 cm of straw and 6 cm of shredded paper.

3.3.3.3 Other poultry

Ducks kept for meat or egg laying are reared in a similar fashion to broilers, with straw or woodchips used as bedding materials. Broiler and layer breeding birds tend to be kept in deep litter houses, although at lower stocking densities than laying hens, and hence the houses tend to be much colder in winter. Breeding birds usually have a one year lifespan and houses will be emptied approximately once a year.

3.3.3.4 Poultry manure properties

Fresh laying hen droppings have a typical dry matter content of about 15-20% (Elson, 1998). The material is colloidal, with the water and solids dispersed in a jelly-like mass. Nitrogen is excreted as uric acid which is transformed over time to ammonium-N, and as organic bound N. Manure pHs are generally in the range 6.5-8.5. Laying hen manure is also likely to contain a certain amount of wasted feed, feathers and eggs, as well as excreta.

The initial moisture content is mainly influenced by nutrition, whilst the drying rate is affected by the external climate, house environment, ventilation rates and manure handling system. Stilt houses usually tend to produce drier manures than deep pit or belt-scraped houses (Table 18), although more modern houses with on-belt drying systems will also produce drier manures.

Table 18. Selected properties of different poultry manures collected in a survey of 100 farms in England and Wales and 25 duck manures

Stock type/management system (no. of samples)	Dry matter (%)	Total N (kg/t fresh weight)	Ammonium-N (kg/t fresh weight)	pH
Layer - deep pit (44)	36	21	8	8.2
Layer - belt scraped (27)	29	17	5	7.1
Layer - stilt house (1)	80	28	2	8.2
Layer - perchery (5)	40	22	3	6.7
Layer - free range (4)	58	34	5	8.0
Broiler litter (14)	64	33	6	8.2
Turkey litter (5)	52	27	7	8.2
Duck (25)	27	6.7	1	8.2

Source: Nicholson *et al*. 1996; Johnson *et al*. 1999.

Layer manure collected in deep pit houses will be protected from the extremes of temperature. In some deep pit houses which have good aeration and in stilt houses, manure can heat up in the centre of the heap. Few data are available on the temperatures achieved or the time for which they are maintained. However, in one study conducted for MAFF by ADAS (WA0638) temperatures were measured in the top 2 cm of aerated and non-aerated manure in a deep pit house from April to August. The mean temperature in the aerated manure (24°C) was lower than that in the non-aerated manure (29°C) with maximum temperatures of 29°C and 33°C measured, respectively. It is important to note that not all the manure will reach the highest temperatures (i.e. manure deposited at the tail end of a production cycle and manure at the heap edges). The heating process drives off water (steam can be observed) drying the manure, and ammonia is lost. Manure in poorly aerated deep pit heaps will undergo less heating.

Litter in a broiler or turkey house can be maintained in a friable state through attention to house humidity by controlling ventilation rates, artificial heating in the first few weeks of the crop, prevention of water spills and condensation, and renewal of patches of poor litter (Hartung, 1994). Litter quality is affected by choice of bedding material

and depth, stocking density, feed quality and bird health (Johnson *et al*. 1999). Typical broiler and turkey litter properties are given in Table 18.

Duck manure tends to be wetter than broiler litter (Table 18) as ducks require considerably more water. Duck manures also have lower ammonium-N contents than broiler litter, and in this respect are more similar to cattle or pig Johnson *et al*. 1999).

3.3.4 Sheep

In 1997, government statistics indicated that there were about 30.4 million sheep and lambs in England and Wales, producing an estimated 1.3 million tonnes of handled manure annually (Pain *et al*. 1998) as straw-based FYM.

3.3.4.1 Timing and duration of housing

Housing sheep during winter has a substantial impact on grassland management, increasing the area available for grazing in spring at the time of maximum lamb growth rates. Ewes may be housed during lambing or overwinter to make flock management easier. In a conventional spring lambing flock the house is likely to be occupied by the ewes for 10-13 weeks (from late December or January) depending on the spread of lambing. In an early lambing flock where the ewes and then growing lambs are kept inside, the house is likely to be used for 4-5 months from December to April/May (Pain *et al*. 1998).

3.3.4.2 Types of sheep housing

In general, sheep housing is covered and varies in sophistication from polythene tunnels to steel framed buildings, which rely on natural ventilation. Most UK sheep houses use straw bedding over an earth or rammed hardcore base. Slatted systems are common in Europe but interest in the UK is largely confined to Scotland where the cost of straw is high. There are a few uncovered yards mainly in the south of England on free-draining soils.

Even on a silage based diet, sheep dung has a solid form. Under slatted flooring, it will build up to a depth of 25-35cm over a 90 day winter period. With a straw based bedding system, the recommended use is about 50 kg straw per ewe over the same period (ADAS, 1987). Removal of dung either from straw based systems or under slats is not usually necessary during the normal housing period, unless there is a specific disease problem.

When sheep are housed intensively there is an increased risk of infectious diseases spreading (Slate & Stubbings, 1994). Sheep should only be housed with dry fleeces to avoid substantial water loads wetting the straw and increasing the risk of infection. During lambing, pens containing plentiful straw can be erected in the main shed to aid management. Afterbirths should be removed regularly, lambing pens disinfected and straw changed between ewes. Poor hygiene can lead to *E. coli* infections in lambs.

3.3.4.3 *Manure analysis*

There are no standard figures available for analysis of sheep manure, although it is normally assumed to be similar in nutrient content to cattle FYM.

3.3.4.4 *Grazing sheep*

Sheep graze outdoors for the majority of the year. In extensive sheep production systems, they tend to be on relatively poor land (e.g. heath/moor) which is unlikely to be used for other purposes (apart from the grazing of other livestock). In lowland sheep production, the animals graze on grassland for the majority of the year (see section x.x on dairy cattle grazing), but may be moved to forage crops (e.g. stubble turnips, sugar beet top residues) in winter. The land may then be returned to the normal farm rotation growing combinable or vegetable/salad crops.

3.4 Manure storage

3.4.1 Slurry storage

The MAFF Water Code (MAFF, 1998b) provides general guidance on the design and building of slurry storage facilities. The Control of Pollution (Silage, Slurry and Agricultural Fuel Oil) Regulations 1991(SF, 1991) require that new or substantially reconstructed stores must normally provide at least 4 months slurry storage capacity. Recent estimates on the volume of slurry stored in the most commonly used stores, for different livestock classes are summarised in Table 17. Most slurry (67%) is stored in earth banked lagoons, with 24% in above ground circular tanks and <10% (all cattle slurry) in weeping wall stores.

Table 19. Stored volumes ($m^3 \times 10^6$) of slurry in England and Wales in 1999

Stock type	Circular tank	Lagoon	Weeping wall
Dairy cattle	4.79	10.71	1.80
Non-dairy cattle	0.27	3.30	0.45
Pigs	0.41	1.49	-
Total	5.47	15.50	2.26

Source: Nicholson *et al* (1999)

The addition of waste milk, whey or silage effluent to slurry is not recommended as lethal gases may be released (ADAS, 1998a), although these practices may occur on some farms.

3.4.2 Transferring slurry to storage facilities

For dairy cattle, slurry is normally transferred from housing into a reception pit or directly into the storage facility using a tractor mounted scraper. For most pigs and some cattle systems, slurry is transferred from housing and emptied into a reception

pit outside the main store using a system of underground transfer channels. A layer of slurry usually remains in the channel base for lubrication.

3.4.3 Below-ground tanks

Below ground tanks are often used to store small amounts of dilute slurry, runoff or washings for a short time (10 days). They can also be used as reception pits to collect slurry before it is pumped to an above ground store. Reception pits are generally covered with a grid to prevent long bedding fibres or feed entering the store. A pump is used to move slurry from the reception pit to the store or to a tanker/irrigation systems for spreading, or to recirculate the contents of the pit. It is recommended that slurry is thoroughly mixed before being added to the main store, and additional water may sometimes be added to cattle slurry in dry weather to improve flowability. Reception pits built since 1991 are required to hold at least 2 days of slurry production (including rainfall).

3.4.4 Above ground circular stores

Above ground circular stores are normally made from steel or concrete. Depths can be up to 6m with the slurry surface completely uncovered, and as a consequence rainfall is also collected in the tank. Normally a reception pit (see section 3.4.2) is located next to the store and slurry is pumped from this in to the main tank.

The contents of the store can be recirculated using the filling pump, propellers or by 'bubbling' relatively small amounts of air. This breaks up any surface crust that has formed and mixes sediment that has collected in the base of the tank to give a more uniform material. The MAFF Air Code recommends that slurry should be mixed when there is minimum risk of causing odour nuisance (i.e. sunny, windy days), and preferably only prior to when the tank is going to be emptied (MAFF, 1998). It is recommended that slurry stores should be completely emptied at least once a year, cleaned and checked for damage. However, in practice, it appears that many farmers never empty their slurry stores.

In future, IPPC (Integrated Pollution Prevention and Control) legislation to reduce ammonia emissions may force pig farmers to cover slurry stores with purpose built covers, although this does not happen at present in this country. In the Netherlands and Belgium this has sometimes led to the build up of H_2S and sulphuric acid, which may accelerate tank corrosion (Nicholson *et al*. 1999).

3.4.5 Weeping wall stores

Weeping wall stores are often used for cattle slurry which contains a lot of straw bedding material. They are built above ground on a concrete base with walls about 2-3m high. The liquid portion of the slurry drains through narrow gaps in the store walls and collects in an underground storage tank, whilst the more solid fraction is retained and gradually dries out until it resembles FYM. Rain falling on the store will drain out into the tank during storage. The stores contents are not usually emptied during winter as this cannot be done safely until the contents have dried out enough (usually from early summer onwards).

3.4.6 Earth banked compounds or lagoons

Earth banked stores can be used to hold slurry that contains bedding, dilute slurry, separated liquids or dirty water. They may be lined using compacted clay or impermeable synthetic liners to prevent seepage. Compounds are used to contain solid or semi-solid materials and can be up to 3 m deep. A strainer box can be placed in the base of the compound to collect excess liquid which can then be removed by a tanker for spreading. Lagoons are used too for liquid storage and can be up to 4 m deep. To break up crusts and incorporate settled solids, the contents must be mixed before emptying - this is often done using tractor driven mixing equipment. Mechanised equipment (e.g. diggers and backacters) is used to empty the settled solids from the base of compounds and lagoons.

Again, IPPC regulations may mean that in future pig farmers are encouraged to cover lagoons (e.g. with floating covers, oil etc.) to minimise ammonia and odour emissions. However, at present, compounds and lagoons are uncovered in the UK.

3.4.7 Slurry treatment

3.4.7.1 Mechanical separation

Mechanical separation takes coarse solids and fibre out of slurry to give a liquid fraction (1-6% dry matter) that can easily be pumped, and a solid fraction (10-20% dry matter) which can be stacked and stored in a similar way to FYM. Separated liquids are less likely to form crusts or to have solids separating out during subsequent storage, reducing the need for in-store mixing. Mechanical separation is usually required before aerobic treatment.

3.4.7.2 Anaerobic digestion

Anaerobic digestion (AD) uses microorganisms to break down organic substances in a heated enclosed digester vessel at temperatures between 25 and 70^{o}C. One of the products of the process is biogas, a mixture of methane and carbon dioxide. Digestion can only effectively be carried out on slurries amenable to pumping with an optimum dry matter content of 6-8%. However, the majority of cattle and pig slurries could in theory be subjected to this process, provided that excess bedding was excluded.

The process can be either mesophilic (25-45^{o}C) or thermophilic (55-70^{o}C). Although the latter process gives higher gas yields, the equipment is more costly to install. All digesters which are commercially operational in the UK work on a continuous process basis, with a nominal retention time of 12-20 days; the lower figure for pig slurries, the higher for cattle slurries (MAFF, 1998). Typical farm scale mesophilic digesters involve a mean 15 day slurry retention time at 35^{o}C. Some centralised mesophilic AD plants in have an additional 70^{o}C pasteurisation process built in which adds significantly to capital costs. In thermophilic digesters, farm slurries would be retained

for a minimum of 10 days at 55^0C**.** Slurry ammonia concentrations may increase during digestion (by 10-15%) however there the effects on slurry pH are not clear (R. J. Nicholson, pers. comm.). The digestion process does not significantly reduce the volume of the slurry nor its total nitrogen content.

3.4.7.3 *Aerobic treatment*

Aerobic treatment of slurry is normally carried out only for odour control purposes and is generally only suitable for separated slurry or dilute effluents (<3% dry matter) containing no bedding (MAFF, 1998). Unseparated pig slurry can be aerated, but cattle slurry which is generally higher in dry matter content 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, ranging from blowing compressed air through porous diffusers with very small outlets, or entraining air in a fast moving stream of liquid in submerged nozzles or floating devices with discs or rotating impellers (Cumby, 1987). Power for these devices is provided by electric motors. Continuous flow systems can reduce slurry odours with a mean retention time of 1-2 days, provided that a reasonable constant and well mixed flow of slurry is maintained. Temperatures in the aerated slurry will rise by 5-25^0C depending on the slurry analysis, degree of aeration, tank insulation and ambient temperature. There is some suggestion that aeration and increased residence time may cause a pH rise (R. J. Nicholson, pers. comm.).

3.4.7.4 *Additives*

Several kinds of slurry additive are available which are claimed to reduce odours and/or ammonia emissions during storage. These include :

- Digestive additives - microbes and/or enzymes
- Strong acids
- Base precipitating salts
- Adsorbents - e.g. zeolites, peat
- Urease inhibitors

- Plant extracts - can be added to animal feeds or to manure
- Disinfectants
- Oxidising agents
- Masking agents

Current MAFF funded research is investigating the effectiveness of a range of slurry additives (Hobbs, 1999). Of particular interest for reducing pathogen levels would be substances which alter the slurry pH or those which affect the composition of the bacterial population. Additives are not currently widely used in England and Wales. Electolytic methods are also available for treating slurry. These involve using copper electrodes immersed in a treatment tank which is claimed to reduce odour nuisance.

3.4.7.5 Analysis of treated slurry

Analysis of typical separated cattle slurries are given in Table 20.

Table 20. Selected properties of separated cattle slurry

Slurry type	Dry matter (%)	Total N (kg/t fresh weight)	Ammonium -N (kg/t fresh weight)
Strainer box[1]	1.5	1.5	1.1
Weeping wall[1]	3	2.0	1.4
Mechanically separated[1]	4	3.0	1.5
Slurry solids[1]	15	5.0	1

[1]Source: MAFF, 1994

There is less information on the effects of other treatments on cattle slurry composition, although anaerobic digestion leads to a decrease in total N of between 3 and 9%, a decrease in organic N compounds and an increase in ammonium-N (NH_4-N) contents (Meer, 1981).

3.4.8 Dirty water

Dirty water generally contains less than 3% dry matter and is made up of water contaminated by manure, urine, crop seepage, milk, other dairy products or cleaning materials. Dirty water is a particular problem on dairy farms in the west, where over-winter (October-March) rainfall may be 600-1000 mm. The biochemical oxygen demand (BOD) and ammonium-N (NH_4-N) concentration in dirty water can vary widely with BOD in the range 240-31,000 mg/l and NH_4-N in the range 50-1,800 mg/l (Cumby *et al*. 1992).

Small volumes of dirty water can be collected and stored with slurry, provided that the store is big enough. However, many sites choose to have separate systems for dirty water storage. Most dirty water is regularly applied to land using a low rate irrigation system, although it may be stored where irrigation to land would pose a runoff problem. Estimates of the volume of dirty water stored separately from slurry in circular tanks or lagoons are 1.9 Mm^3 for dairy cattle and 0.12 Mm^3 for non-dairy cattle (Nicholson & Brewer, 1997).

3.4.8.1 Dirty water treatment

Treatment systems for dirty water aim to reduce the pollution potential by settlement or using the activity of bacteria. The treated dirty water can then be discharged to surface waters, spread to land or put into a public sewer.

- *Barrier ditches* - allow liquid to settle in a large barriered section of a ditch for 90 days, followed by aerobic treatment in a free flowing section of the ditch at least 300 m long.
- *Reedbeds* - pass dirty water through the roots of reeds growing in gravel or soils. They can reduce BOD but are not as effective in reducing ammonium-N concentrations (MAFF, 1998).
- *Aeration* - involves mixing and bubbling air through dirty water using a mechanical aerator.

Very few dirty water treatment systems are in use due to their high capital and running costs, and the difficulty of obtaining a discharge consent from the Environment Agency.

3.4.9 Solid manures

Solid manures from cattle, pig, poultry and sheep production may be stored using the following systems :

- concrete pad - with leachate collection tank
- concrete pad - no leachate collection tank
- field heap on soil - same site each year
- field heap on soil - different site each year
- roofed store with concrete base

Specially designed solid manure stores have a reinforced concrete base, with between one and three walls, each 2-3m high. The width of the store is usually 10-15 m. Liquid runoff is collected in a below-ground tank or into a dirty water collection system.

An estimate of the volumes of solid manure stored on concrete pads and in field heaps is given in Table 21 (Nicholson *et al*. 1999). This shows that the majority (79%) of solid manures are stored in field heaps rather than on concrete pads.

Table 21. Estimates of volumes of solid manure ($m^3 \times 10^6$) stored in England and Wales

Stock type	Concrete pad	Field heaps
Dairy cattle	0.96	3.00
Non-dairy cattle	1.62	7.25
Pigs	0.68	1.22
Laying hens[1]		0.18
Broilers[1]		0.52
Total	3.26	12.17

[1]No estimate was made of the amount of poultry manures stored on concrete pads

Source: (Nicholson, 1999)

Solid manures are normally left undisturbed except during the addition of new material when houses are emptied or they are moved to outlying fields for temporary storage prior to land application. Farmyard manure and poultry manures are generally stored outside, although a number of the major laying hen companies have built stores to ensure that their layer manure is kept dry prior to land application, for handling and odour control purposes.

The extent of composting and the temperatures attained will depend on the composition of the material (e.g. C:N ratio, moisture content, density) and management (e.g. turning to promote aeration). Data from a recent MAFF-funded study (ADAS, unpublished data) showed that unturned pig FYM stored in 1t heaps attained a temperature of c. 60°C after 3 days, and maintained a temperature of over 50°C for about 2 weeks, before declining to c. 25°C. The same study found that 50 m^3 heaps of unturned broiler litter reached 48°C after 2 weeks, but layer manure only reached temperatures of 25-36°C. There is little information on the variation in temperature between the inner and outer layers of a single manure heap and on changes in temperature over the duration of storage.

3.4.10 Current manure storage practices

3.4.10.1 *Slurry and dirty water*

On removal from houses, slurry may be held in different types of store, although results of the Manure Management Practices survey (Smith *et al*. 2000a,c) suggested that quite a large proportion of units have no, or minimal slurry storage, particularly taken together with units on which there is only a small below ground tank (Tables 22 and 23).

A large majority of farmers with earth banked lagoons never stir the store, although with above ground tanks almost 90% of cattle and 70% of pig slurry stores are regularly or occasionally agitated (Smith *et al* 2000a,c). Less than 10% of farmers used a mechanical slurry separator (ADAS 1997a, ADAS 1998a,b). About 35% of beef farmers, 58% of dairy farmers and 87% of pig farmers reported that their slurry stores were never empty. Less than 10% of cattle farmers and 16% of pig farmers transported slurry off-farm. The majority (77%) of beef farms and 23% of dairy farms had no separate storage facilities for dirty water or less than one months storage capacity (ADAS 1997a; ADAS, 1998a;b;c), with the dirty water either applied directly to land or added to the slurry store (Table 24).

3.4.10.2 *FYM*

Nicholson *et al*. (1999) estimated that around 20% of cattle FYM and 36% of pig FYM was kept on concrete pads with the remainder stored in fields heaps. The Survey of Manure Management Practices (ADAS 1997a,b ADAS, 1998a,b,c) suggested that c.70% of cattle farmers and 31% of pig farmers spread at least some of their FYM directly to land on removal from housing (Table 25). About 3% of cattle farmers and 22% of pig farmers transported FYM off-farm.

Table 22. Estimated proportion of slurry held in different types of store

Slurry type	No slurry store	Circular tank	Earth bank lagoon	Below ground tank	Weeping wall
Beef	25	15	15	30	13
Dairy	18	31	30	5	16
Pig	17	23	20	40	-

Source: Smith *et al*. (2000a,c)

Note : Some farms have more than one type of slurry store

Table 23. Estimated capacity of cattle slurry stores (% manure)

Number of months	Beef slurry	Dairy slurry
<1 month	25	16
1-2 months	12	11
3-4 months	32	35
5-6 months	25	22
>6 months	6	16

Source: Smith *et al* (2000a,c)

Table 24. Capacity of dirty water stores (% survey respondents)

Number of months	Dairy farms	Beef farms
No storage/<1 month	23	77
1-2 months	12	8
3-4 months	31	8
5-6 months	17	3
>6 months	14	3

Source: Smith *et al*. (2000a,c)

Table 25. Proportion of cattle FYM removed from buildings and spread directly to land (% survey respondents)

Proportion removed	Beef FYM	Dairy FYM
<25%	26	36
25-50%	10	10
50-75%	22	16
>75%	42	38

Source: Smith *et al*. (2000a,c; ADAS 1998a,b)

3.4.10.3 *Poultry manure*

Once manure has been removed from poultry houses, it may be stored for varying periods of time before being spread to land, but most commonly for a period of 3-6 months (Table 26). The Manure Management Practices survey results (Smith *et al* 2000b) showed that c.60% of farmers stored manure before spreading, with the remainder either spreading the manure immediately or transporting it off-farm. Of the farmers who stored manure, the majority (>80%) stored some or all in the yard or field, with the remainder stored undercover (ADAS 1997b. Between 39 and 57% of the farmers surveyed transported some or all of their poultry manure off-farm (ADAS 1997b).

Table 26. Poultry manure (layers and broilers) storage capacity

Number of months stored	%manure
No storage	43
1-2	14
2-3	7
3-6	28
6-9	3
>9	6

Source : Smith *et al* (2000b)

3.4.10.4 *Sheep manure*

Less information is available on sheep manure storage, however Pain *et al*. (1998) indicated that sheep FYM was typically stored in field heaps for about 60 days.

3.4.10.5 *Summary of manure storage practices*

The most common type of slurry store is the earth banked lagoon, although above ground circular stores and underground tanks are also widely used. Weeping wall stores are only used on cattle farms. Slurry treatment (e.g. aerobic and anaerobic digestion, chemical additives) is not widespread, although a number of farms do use mechanical slurry separators to aid handling.

A single slurry store or solid manure storage heap may consist of manures from different ages and classes of animal, from several different houses and be stored for different lengths of time. Many farmers reported that their slurry stores were never empty and very often not stirred or only occasionally stirred, implying that due to settlement the material within would be 'layered' in terms of its dry matter content and nutrient analysis.

A relatively large proportion of poultry manure, slurry and FYM is spread straight to land after it is emptied from the animal housing, because farmers do not have adequate storage capacity for liquid manures and for the greater convenience of moving solid manures straight from the building to land application. Transportation of manure off-farm is a common practice, creating a route for the potential spread of pathogens to farms other than those where they originated. Transportation is most widespread on poultry and pig farms, with dairy and beef farmers much less likely to transport manures off-farm (Table 27). Where a farm transports manure, a large proportion of production (45-100%) is involved.

Table 27. Transportation of manures off-farm

Manure type	Proportion of farmers transporting manure off-farm (%)	Proportion of manure transported (%)
Layer manure	39	89
Broiler/turkey litter	57	86
Pig slurry	16	74
Pig FYM	22	78
Dairy slurry	8	62
Dairy FYM	3	45
Beef slurry	<1	100
Beef FYM	3	75

Source : ADAS 1997a,b; ADAS 1998a,b

3.5 Manure spreading

3.5.1 Slurry spreading methods

Before land application, slurry must first be transported from the slurry store to the field. There are 4 main types of slurry transport system:

- *Vacuum tanker* - slurry is sucked into the tanker using an air pump to create a vacuum, and emptied using the air pump to pressurise the tanker.
- *Pumped tanker* - slurry is pumped into and from the tanker using a slurry pump.
- *Umbilical hose* - slurry (usually direct from the store) is fed by a drag hose to the tractor carrying the distribution system.
- *Irrigator* - a self travelling machine with hoses fed from a system of underground pipes with a pump near the slurry store.

There are four main types of slurry distribution system. Each can be fitted onto a vacuum or pumped tanker, and can potentially be attached to an umbilical hose.

- *Broadcast spreader* - slurry is forced under pressure through a nozzle, often onto an inclined plate (splash plate) to increase the lateral spread.
- *Trailing hose* - the spreader boom has hoses connected to it which distribute slurry close to the ground in strips or bands
- *Trailing shoe* - the spreader boom has a shoe added to the end of each hose which allows slurry to be deposited under the crop/grass canopy onto the soil.
- *Injector* - slurry is injected into the soil. There two types of injector a) open slot shallow injection up to 5cm deep or b) deep injection to at least 15 cm.

Broadcasting is the most commonly used slurry spreading technique in the UK. However, as pressures to reduce ammonia emissions increase, more farmers will probably move to low trajectory application techniques (trailing hose, trailing shoe, injection).

3.5.2 Solid manure spreading methods

There are 3 main types of solid manure spreader in commonuse (Chambers *et al*. 1999c):

- *Rotaspreader* - side discharge spreader. A spinning rotor throws the manure out to the side of the vehicle as it travels.
- *Rear discharge spreader* - solid manure is delivered to the rear of the spreader where it is discharged either by beaters or spinning discs
- *Dual purpose spreader* - a side discharge spreader with an open top that can handle both slurry and solid manure.

3.5.3 Manure application

Manures are usually applied to arable stubbles or to grass swards, although increasingly slurries and poultry manures are being topdressed onto growing arable crops in spring to make best use of their fertiliser N value and to decrease nitrate leaching losses following autumn/winter application timings.

Following land spreading, solid manures and slurry may be left on the soil/crop surface or incorporated into the soil by a number of methods:

- ploughing (manures will be buried in the soil to a depth of 20-40 cm).
- tining (shallow incorporation to a depth of 10-15 cm)
- rotavation (shallow incorporation to a depth of 10-15 cm)
- discing (shallow incorporation to a depth of 10-15 cm)

Incorporation can be rapid (a few hours after spreading) or delayed (up to months after spreading).

3.5.3.1 Current manure spreading practices

3.5.3.1.1 Slurry and dirty water

Slurry is usually broadcast spread using splash plates inclined for low and high level application, with fewer applications using mobile/static irrigators or injection. Dirty water is spread using broadcast spreading techniques or mobile/static irrigators (Table 30). Applications are made throughout the year depending on crop type, soil conditions and slurry storage capacity (Table 31). Survey results showed that there was a preference for spring application of dairy slurry on forage maize and autumn application of pig slurry on cereals stubbles, whilst slurry spreading to grazing and silage land was more evenly distributed throughout the year (Smith *et al*, 2000a,c).

Using a typical total N contents (MAFF, 1994) for slurry with 6% dry matter, the maximum spreading rates would be c. 110 m^3/ha for beef slurry, c. 80 m^3/ha for dairy slurry and c. 50 m^3/ha for pig slurry. The Manure Management Practices survey results showed that 70% of farmers do not incorporate beef slurry after spreading, and c.40 do not incorporate dairy or pig slurry (Table 32).

Over 5 times the area of grassland receives slurry (pig and cattle) compared with tillage land (Table 33). About 3% of tillage land in any one year receives slurry, with about half of this area being sown to cereals; 15% of grassland receives slurry in any one year.

Table 28. Machinery used for spreading cattle and pig slurry and dirty water (% survey respondents)

Machinery used	Pig slurry	Dairy slurry	Beef slurry	Dirty water (dairy farms)	Dirty water (beef farms)
Injector	4	1	1	-	-
Surface applicator	7	15	9	11	11
Low level applicator*	49	41	53	15	40
Higher level applicator**	25	35	35	12	26
Mobile irrigator	11	5	3	19	12
Static irrigator	5	2	0	16	13

Source: ADAS (1997a,b); ADAS (1998a,b)
*slurry does not reach above tanker/spreader height
**slurry does reach above tanker/spreader height
Note : Response can total >100% as some farms use more than one application technique

Table 29. Timing of slurry, FYM and poultry manure applications (% of total volume applied)

Manure type	Feb-Apr (spring)	May-Jul (summer)	Aug-Oct (autumn)	Nov-Jan (winter)
Layer manure	21	16	44	19
Broiler litter	26	9	50	15
Pig slurry	27	18	35	20
Dairy slurry	40	10	24	26
Beef slurry	46	13	20	21
Pig FYM	17	7	56	19
Dairy FYM	40	10	25	26
Beef FYM	28	10	42	20
Average for all manures	31	12	37	21

Source : ADAS (1997a,b); ADAS (1998a,b)

Table 30. Speed of incorporation of slurry, FYM and poultry manure (% of manure applied)

Manure type	Same day as spread	Within 1 week of spreading	Over 1 week after spreading	Not incorporated
Layer manure	7	56	25	12
Broiler litter	11	61	10	18
Pig slurry	15	27	20	38
Dairy slurry	8	38	15	39
Beef slurry	13	8	9	70
Pig FYM	23	54	17	6
Dairy FYM	9	50	31	10
Beef FYM	6	8	36	50
Average	12	38	20	30

Source : Smith *et al* (2000a,b,c)

Table 31. Crop area (1000 ha) in England and Wales receiving slurry, FYM and poultry manure in 1995

Crop type	Slurry	FYM	Poultry manure
Spring wheat	2.4	2.4	0.4
Winter wheat	20.2	104.3	13.5
Spring barley	7.8	39.0	3.8
Winter barley	13.0	67.1	2.9
Oats	0	9.0	0
Rye	0	0.9	0
Total cereals	*43.4*	*222.7*	*20.6*
Early potatoes	1.0	4.2	0.6
Maincrop potatoes	2.3	19.5	5.4
Sugar beet	4.4	37.2	4.6
Oilseed rape	4.5	29.2	6.2
Linseed	1.4	1.2	0
Forage maize	3.8	10.1	1.2
Turnips (stock)	1.1	3.1	0
Kale and cow cabbage	1.0	4.4	0
Other roots/green crops	1.7	6.4	0.5
Peas	0.7	3.8	0
Beans	1.9	7.1	0
Vegetables (brassicae)	0	0.7	0
Vegetables (other)	0.6	0.8	0
Small fruit	0.3	0	0
Top fruit	0	1.2	0
Other tillage	49.4	68.3	10.9
Total tillage	*117.5*	*419.9*	*50.0*
Grass <5 years	334.8	760.8	36.9
Grass 5 years and over	294.6	619.6	54.2
Total grass	*629.4*	*1380.4*	*91.1*

Source: (Burnhill, 1996)
Note: total area of tillage land = 3,784,000 ha; total area of grassland = 4,154,000 ha

3.5.3.1.2 FYM and poultry manure

FYM and poultry manure applications are made throughout the year depending on crop type, soil conditions and manure storage capacity (Table 28). Applications of cattle and pig FYM are lower during the summer months (May-July) as opportunities for application are limited, and a greater proportion of applications are in the autumn-winter period onto cereal stubbles and prior to root crops. A high proportion of poultry manure is applied in the August-October period to cereal land or land scheduled for potatoes or sugar beet, although applications to grazing land and silage areas are less variable throughoout the year (Smith *et al* 2000b).

Using a typical total N contents (MAFF, 1994) the maximum spreading rate for cattle FYM would be c. 42 t/ha, for pig FYM 36 t/ha, for broiler litter 9 t/ha and for layer manure 17 t/ha. In practice, more pig and dairy cattle FYM is incorporated than beef cattle FYM or poultry manure (Table 29), probably because beef cattle FYM and poultry manure are more likely to be spread to grassland where incorporation is not possible.

More grassland receives FYM and poultry manures than tillage land (Table 31). About 11% of tillage land in any one year receives FYM with about half of this being sown to cereals; 33% of grassland in any one year receives FYM. Only 1.3% of tillage land and 2.2% of grassland receive poultry manure applications in any one year. The largest tillage land area receiving poultry manure applications in 1995 was sown to cereals, with oilseed rape, maincrop potatoes and sugar beet also being important.

3.5.3.2 *Summary*

Slurries and dirty water are usually spread using broadcast techniques (e.g. splash plates adjusted for low or high level application) or mobile/static irrigators, with little use currently being made of low trajectory techniques such as band spreading or deep/shallow injection. Solid manures are spread using rear or side discharge spreaders.

In general, most farm manures are applied to agricultural land in autumn (37%) and spring (31%), with lower amounts applied in winter (21%) and summer (12 %), Table 31. Land growing cereals usually receives most manure in the autumn period due to the availability of cereal stubble, whereas land growing forage maize, potatoes and sugar beet tends to receive a greater proportion of manure applications in spring. Grass for grazing and silage has a more even spread of manure applications throughout the year (Table 32), reflecting the greater amount of opportunities available for land spreading and limited slurry storage capacity on many dairy/beef farms. It is likely that some farmers spread manures at higher than the maximum permissible rate of 250 kg N/ha.

Table 32. Timing of manure applications by crop type (average % of all manure applied)

Crop	Spring (Feb-Apr)	Summer (May-Jul)	Autumn (Aug-Oct)	Winter (Nov-Dec)
Grazing land	31	14	26	31
Grass for silage	34	15	20	31
Forage maize	65	7	4	24
Potatoes	46	2	21	31
Sugar beet	40	3	22	35
Cereals	19	7	61	13

Source: adapted from Burnhill *et al* (1998)

Table 33. Percentage of vegetable crop area receiving organic manure in England and Wales

Crop	FYM	Slurry	Poultry manure	Sewage sludge
Brassicas	9	3	0	<1
Other vegetables	9	2	0	0
Potatoes	27	5	5	<1

Source: adapted from Burnhill *et al* (1998)

For all manure types, a greater area of grassland receives manures than tillage land. For both tillage and grassland, FYM is applied to a greater area than slurry or poultry manure. Of the tillage land receiving manure, about half is sown to cereals with maincrop potatoes, sugar beet, oilseed rape and forage maize also being important. In terms of vegetable crops, a greater percentage of the crop area receives FYM than slurry, and little land will receive poultry manure (Table 33).

The amount of manure incorporated into the soil varied between manure types (Table 32), with a trend for more slurry to be left unincorporated than solid manure because FYM is mainly applied on stubble and slurry on grass. On average 30% of survey respondents did not incorporate their manures at all and only 12% incorporated manure on the same day it was spread.

4. IMPLICATIONS OF CURRENT MANURE MANAGEMENT PRACTICES FOR PATHOGEN SURVIVAL

4.1 ***Introduction***

This section of the report describes the likely effects of current manure management practices to the survival of pathogenic microorganisms in manures during livestock housing, manure storage and land spreading.

The pathogen content of animal manures will be influenced both by the initial pathogen levels in the excreta and by the ways in which the manures are subsequently managed. Manure management can be divided into three phases comprising:

- *Housing*. Includes excretion by livestock and short-term storage in housing. Fresh excreta is continually added to manures in housing and short-term storage, thus housing-phase manures will generally contain the highest levels of microorganisms.

- *Storage*. The storage phase begins when manures are either pumped (slurry) or heaped (FYM) away from livestock housing. Thus during storage, there is no continual addition of fresh manure. Periodically however, batch additions of fresh waste may be added to previously stored material.

- *Application*. Pathogenic microorganisms present in manures have the greatest potential to be distributed into the environment when manures are recycled to agricultural land. Excreta deposited directly onto soil and herbage by grazing animals is considered to be in the application phase.

Because there is considerable variation in manure management practices both between farms and for the same farm at different times of year, it is not possible to describe every potential risk associated with every batch of manure. To simplify this section of the report, the most prevalent pathogens in each livestock type have been identified, and the likely effects of the most commonly used livestock and manure management practices on the levels of these pathogens are then discussed.

4.2 Pathogen incidence and levels in excreta

4.2.1 Cattle

Cattle farming is widely distributed throughout the UK, although there are more herds in the west of the country where climate is wetter and the proportion of grassland is greater. A combination of the large quantity of cattle manure produced (52 Mt in England and Wales), coupled with the potential presence of a range of pathogens, means that cattle manures represent the greatest potential risk for pathogen dissemination to the human food chain.

The human pathogens which have been isolated from cattle manure are *Salmonella*, *Listeria*, *E. coli* O157, *Campylobacter*, *Cryptosporidium* and *Giardia*. The available UK prevalence data suggest that up to 16% of dairy cattle may have faeces infected with *E. coli* O157, with a lower incidence (13%) amongst beef cattle (Chapman *et al.* 1997). In contrast, the incidence of *Salmonella* is less than 0.1 %, with little similar data available on the incidence of other pathogens in cattle faeces in the UK

The levels of pathogens in cattle excreta depend on animal age, diet and management, as well as regional and seasonal factors. There is good evidence to suggest that shedding of *E. coli* O157, *Campylobacter* and *Cryptosporidium* is greatest in young animals, and higher *E. coli* O157 levels have been found in dairy herds than in beef herds. There is also evidence for a peak in *E. coli* O157 and *Campylobacter* in early summer and a second peak in autumn, possibly reflecting the movement of cattle to and from winter housing. Stressed animals (eg. where rations were withdrawn prior to slaughter) have been found to shed more *E. coli* O157 than non-stressed animals (section 2.4.4). Little is known about shedding rates of other pathogens, except that *Listeria monocytogenes* in cattle faeces was found to be most prevalent in winter which was linked to the feeding of silage in the diet (section 2.3.1).

4.2.2 Pigs

The pig industry in the UK tends to be largely concentrated in East Anglia and Humberside, although there are units elsewhere in the country. Pigs produce the second largest amount of manures (10 Mt in England and Wales), although this is still only one fifth of the amount produced by cattle.

Despite a low prevalence (0.4%) of *E. coli* O157 in pig faeces (Chapman *et al.* 1997), and some reports from Europe of *Campylobacter* carriage in pigs (section 2.2.2), the major pathogen of concern in pig manures is *Salmonella*. There were 323 reported isolations of *Salmonella* in pigs in the UK in 1998 (Veterinary Laboratory Agency of the Ministry of Agriculture Fisheries and Food 1998) with 37% of all isolates typing as multi-drug resistant *S. typhimurium* DT104. There are no reports of whether pig age, diet or management affect *Salmonella* shedding rates, or of seasonal trends.

4.2.3 Poultry

The poultry flock in England and Wales produces around 4 Mt of manure annually, less than 10% of the volume produced by cattle. There is a trend for poultry production to be concentrated in East Anglia, North Lincolnshire, West Lancashire, the Welsh borders and parts of south west England.

The most commonly found pathogens in poultry manure are *Salmonella* and *Campylobacter*. Nowadays breeding flocks are subject to statutory testing for *Salmonella* and it has become commonplace to vaccinate laying hen pullets against *S. enteritidis*. A combination of these two practices has led to an overall drop in the number of *Salmonella* infections in poultry over the last decade, and in 1998 there were under 1250 poultry notifications for the entire UK (Veterinary Laboratory Agency of the Ministry of Agriculture Fisheries and Food 1998). There is evidence to suggest that poultry farms are frequently infected with *C. jejuni* and *C. coli* and that the manures can harbour large numbers of these bacteria (section 2.2.3). Whilst other pathogens may be present in poultry and poultry manures, they are not generally

thought to be a widespread problem. To date, no incidence of verotoxin-producing *E. coli* O157 has been reported in UK poultry manures.

4.2.4 Sheep

The relatively small quantity of handled sheep manure produced (1.3 million tonnes in England and Wales), means it represents a low potential risk for pathogen dissemination to the human food chain. However, excretion during grazing will be an important route for potential pathogen transfer.

The pathogens which have been isolated from sheep manure are *Salmonella*, *E. coli* O157, *Campylobacter* and *Cryptosporidium*. The available UK prevalence data suggest that c. 2% of sheep may have faeces infected with *E. coli* O157, with the incidence of Salmonella < 0.1 % There is good evidence to suggest that shedding of *E. coli* O157, *Campylobacter* and *Cryptosporidium* is greatest in lambs, and may be triggered by birth. Stress (e.g. fasting) has been shown to increase *E. coli* O157 and *Salmonella* shedding rates (Grau *et al* 1969), although little is known about shedding rates of other pathogens.

4.3 Effect of housing on manure pathogen levels

4.3.1 Cattle

Approximately half of the cattle manure in England and Wales is produced as FYM (a mixture of bedding and excreta), with about 60% of this from beef cattle. FYM tends to be removed infrequently from cattle sheds. Fresh straw is added when bedding becomes heavily soiled, thus the excreta component of the manure will range from fresh to several months old. Over this time it is likely that there will be a decrease in the pathogen load of the FYM.

Most cattle are given straw bedding, which has been found to support less faecal coliforms than other bedding materials such as shavings or sawdust (Table 2). Limited

composting of bedding leading to raised temperatures is likely to decrease the survival rate of heat sensitive pathogens. The degree of composting that occurs in the house will depend on the degree of compaction and the moisture content, which in turn will depend on the amount of bedding supplied and the stocking density. Higher straw addition rates are likely to increase the amount of composting as this will permit more air to circulate by improving the structure of the manure. Where stocking densities are high or where houses are emptied infrequently, the manure will probably become compacted by trampling, discouraging the composting processes.

Even if no composting occurs, at ambient summer temperatures it is likely that most *E. coli* O157 in the bedding will be destroyed after a few months. However, during cooler winter periods survival times could be longer, although *E. coli* O157 numbers will still decline over time. There is no information available on the fate of *Salmonella* in soiled bedding, however, it is likely that *Salmonella* would decline at a faster rate than the more hardy *E. coli* O157. In one study, *Cryptosporidium* oocysts declined rapidly in mixtures of manure and bedding in a cattle pen (Svoboda *et al*. 1997) . In contrast, it has been demonstrated that thermophilic *Campylobacter* could still be isolated even from composted bedding (Stanley *et al*. 1998).

Cattle on slurry systems will probably be fed silage based diets, which have been linked with elevated *Listeria* shedding rates (Pell 1997*)*, although there is no evidence to suggest that levels of other pathogens would be affected. Below-house slurry pits are generally emptied more frequently than straw yards, most commonly every two or three months. Nevertheless, during the periods the slurry is in the pit below the house, there will be some overall reductions in pathogen levels.

FYM or slurry removed from the house and spread directly to land with no interim storage is likely to contain the highest number of pathogens. Survey data suggest that land spreading FYM and slurry with no or little storage is a relatively common practice for farmers who do not have adequate slurry storage capacity or who prefer the convenience of moving solid manures straight to land application (section 3.4.10.2).

Some cattle manure may be exported from the originating farm prior to land application which creates a potential route for pathogens to spread to neighbouring farming land and livestock. To minimise the risk of pathogen transfer between farms we recommend that manures are stored or treated before export or on arrival at the receiving farm.

4.3.2 Pigs

Approximately 70% of pig manure in England and Wales is produced as FYM. Straw based FYM tends to be removed regularly from pig housing, usually at daily or weekly intervals, and it is unlikely that there will be significant changes to the pathogen load of the FYM whilst it is in the house. There is no evidence to suggest that pigs on slurry-based systems will excrete different levels of pathogens to those on FYM systems. Below-house slurry pits are generally emptied at least monthly. There are likely to be small reductions in pathogen numbers during the period it is held in the slurry pit.

As with cattle manure, pig FYM or slurry removed from the house and spread directly to land with no interim storage is likely to contain the highest number of pathogens, and survey data suggest that this is a relatively common practice. More pig farmers transport manure off farm than cattle farmers because of the smaller land areas associated with pig units. Storage or treatment of pig manures, either at the exporting or receiving farm, prior to land spreading is also strongly recommended.

4.3.3 Poultry

4.3.3.1 Broilers and turkeys

Broiler chickens and turkeys, which generate just over half the poultry manure produced in the UK, are usually housed on the floor of large sheds covered in litter (straw or wood shavings) at constant temperatures of c. 21^{o}C (broilers) or 12-20^{o}C (turkeys). There are health implications for birds kept on wet litter, so most farmers

will supply sufficient bedding to their flocks such that when the manure is removed from the house it generally has a dry matter content of c. 60%. There are regulations controlling the maximum broiler and turkey stocking densities, but higher stocking densities will usually lead to wetter manures due to the greater proportion of excreta.

Poultry litter at c. 60% dry matter and a pH of 7-8 is unlikely to contain high levels of dissolved ammonia, and hence there will be little reduction in the numbers of *Salmonella* or *Campylobacter* by 'natural disinfection'. Most faecal pathogens cannot survive dry conditions, although it is not clear from the literature what the 'critical' level of moisture is to ensure an effective kill. However, *Salmonella* in poultry litters has been found to be especially resistant to desiccation (Janning *et al* 1994; Halbrook *et al*. 1951). Heat is generated by natural composting of the litter in the houses, but it is possible that *Salmonella* could survive for several months in dry areas where temperatures are lower. Despite their resistance to moderate heat stress, the dryness of the litter may help to control levels of thermophilic *Campylobacter.* Although there is no specific information available on the susceptibility of *Campylobacter* to drying in poultry manures, it has been found to reduce numbers in sheep faeces (Jones *et al.* 1999).

4.3.3.2 *Laying hens*

The most common manure management systems for laying hens in the UK are deep pit and belt-scraped houses. In deep pit houses, manure collects in heaps underneath the houses for periods of up to a year. In belt-scraped houses, some drying of manures can occur, as it is deposited in fairly thin layers on belts which are emptied 1-2 times a week. Nevertheless, it is unusual for manures to dry completely even in houses which have forced aeration systems.

Research has shown that over one week, a 1-2 log reduction in *Salmonella* levels in poultry manure occurs at 20^{o}C (Himathongkham *et al.* 1999a), similar to temperatures found in laying hen houses. In one study, the mean temperature of manure under a deep pit house was measured at 29°C, which if typical of the industry, should be

sufficient to significantly reduce *Salmonella* numbers over the year they remain in the pit. However, some parts of the manure may not reach these temperatures and fresh manure will be present in the uppermost layers. For belt-scraped systems in summer, where manures generally remain on the belts for a week, the effect of ambient temperature is unlikely to stress *Salmonella* or *Campylobacter* populations sufficiently to significantly lower their numbers. The winter practice of frequent belt scraping followed by outside storage at low temperature is likely to further prolong the survival of both *Salmonella* and *Campylobacter* in the manure.

The UK Code of Practice (MAFF, 1998) recommends that manures in poultry houses are managed to keep them as dry as possible both in order to maintain bird health and to reduce environmental problems associated with odours and ammonia emissions. A consequence of this advice is that *Salmonella* may survive for longer in drier than in wetter manure. Moisture favours production of dissolved ammonia which has known antibacterial properties (Himathongkham *et al*. 1999a).

As for cattle and pig manures, poultry manures should be stored prior to land spreading. Transportation of poultry manure off-farm is common because many poultry producers have very little land associated with their units where manures could be spread.

4.3.4 Sheep

In the UK, sheep are usually housed only during the winter, around lambing time when levels of pathogens in the excreta are likely to be highest. They are kept on straw bedding, and manure from the houses will probably only be cleaned out when the sheep are returned to the fields in spring. During the housing period, the manure is likely to compost to some extent in the house in a similar fashion to that already described for cattle manures (section 4.3.1). Partial composting will reduce the numbers of pathogens.

4.4 Effect of storage on manure pathogen levels

4.4.1 Slurry storage

Untreated slurry stored in tanks or lagoons is unlikely to rise in temperature above ambient levels, thus the survival time of temperature sensitive pathogens will depend largely on the time of year. There are little data on pathogen survival times in slurry under farm conditions, although *Campylobacter* levels are known to be greater in winter than summer (Stanley *et al* 1998b), and they have been detected in samples of 'matured' cattle slurry (Stanley *et al* 1998a). In the laboratory, *Salmonella* has been found to survive for as long as 20 weeks in slurry stored at 5°C, whilst at 30°C no *Salmonella* were found after 3 weeks (Jones 1976). A link between increased slurry dry solids content and *Salmonella* survival was also reported by these authors and by Provolo *et al* (1999). No reduction in *Listeria* numbers was found after 84 days storage at 4°C, whilst the average time for a 1 log reduction at 17°C was 20 days (Kearney *et al* 1993). Viable *Listeria* have been isolated in slurry after 60 days storage at 15°C (vanRenterghem *et al* 1991). It is more difficult to assess the time required for reductions in *E. coli* O157 since the only study which monitored their decline in cattle slurry, vigorously agitated the sample throughout (Maule 1996). Under these conditions, no viable *E. coli* O157 were recovered after 9 days.

Most pathogens in untreated slurry will probably have declined to very low levels after 3 months storage, although a substantial number of UK farmers will not have this amount of slurry storage capacity. Slurries should therefore be stored for as long as practically possible prior to land spreading (at least 1 month), to allow as long a time as possible for pathogen levels to decline. The evidence suggests that *E. coli* O157 is more prevalent amongst dairy cattle, implying that it is especially important that dairy farmers have adequate slurry storage facilities.

Some farmers agitate or stir slurries to homogenise them, usually just prior to spreading. This is not likely to affect pathogen levels unless agitation is prolonged or vigorous enough to aerate the slurry , which is known to reduce the levels of

pathogens. The sterilising influence of UV light is only likely to affect pathogens in a very thin surface layer of slurry, so covering slurry stores is unlikely to affect pathogen survival in the bulk of the slurry. However, appropriately chosen covers may allow slurry to retain heat more effectively, which in turn may reduce pathogen levels.

The pH of untreated slurry is usually in the range pH 6.5 - 8.5. At these levels, the amount of dissolved ammonia in the slurry will probably not be high enough to have a significant disinfectant effect. Slurry treatments which increase the pH may also increase dissolved ammonia concentrations and have an influence on pathogen survival, although ammonia emissions may also be increased as a consequence. Slurry additives are not widely used in the UK at present, although their effects on pathogen survival would be worth investigating especially if minimum storage retention times could be decreased.

4.4.2 Solid manure storage

During storage of FYM (or separated slurry solids), heat-generating composting processes are almost certain to occur. The efficiency of composting will depend on a number of factors including the straw content, moisture content and frequency of turning - the more efficient the composting, the higher temperatures will be reached and the greater the rates of pathogen elimination. For properly managed manure heaps, temperatures of 55-65°C can be reached and maintained for several days, which will effectively eliminate pathogens.

In the absence of active composting, pathogen levels will decrease over time, but ambient temperature will also play an important role in the rates of decline. Thus there will be seasonal fluctuations in pathogen decline in manure heaps, with the longest survival expected in winter. Under ambient conditions thermophilic Campylobacters and *E. coli O157,* which are more resistant to moderate temperatures than other bacterial pathogens, may survive inside manure heaps for extended periods of several months. *Salmonella* is known to resist drying, and may therefore be able to survive in the drier surface layers of unturned manure heaps for similar periods. Although the

antimicrobial effect of UV radiation is powerful, only pathogens at the very surface of a manure heap will be subject to its sterilising effect.

Research using laboratory stored manures found that at temperatures of 20°C and 37°C in the heap centre, the time taken for a 1 log reduction in *E. coli* O157 numbers was 13.5 and 3.6 days, respectively (Himathongkham *et al* 1999c). A separate study using small cattle and sheep manure piles, under ambient conditions, isolated *E. coli* O157 for up to 47 days from turned cattle manure heaps and up to 4 months in frequently-turned sheep manure heaps (Kudva *et al* 1998). When no turning was performed, *E. coli* O157 could be isolated for up to 21 months from undisturbed heaps. Although the sample numbers are low, these data suggest that *E. coli* O157 can survive for longer in sheep manure than in cattle manure, perhaps as a consequence of lower proportion of straw in the sheep manures creating less favourable conditions for composting.

Other research on stored cattle manure and faeces samples under laboratory conditions has reported *E. coli* O157 survival for between 42 and 99 days, depending on conditions (section 2.4.1).

Numbers of *Cryptosporidium* oocysts decline rapidly in stacked manure heaps. Four weeks at 20°C appears to be sufficient for the total kill of all oocysts (Svoboda *et al* 1997), although there are known problems with the accurate assessment of oocyst viability. *Salmonella* was reported to be eliminated in less than 21 days in heaps of composted pig manure where temperatures reached up to 65°C (Tiquia *et al* 1998), but to survive for 56 days at 4°C (Ajariyakhajorn *et al*. 1997). There is very little information on the survival of other pathogens in FYM heaps.

In the UK, solid manures are usually stored for around 3-6 months and it is likely that most pathogens will have been eliminated by the end of the storage period, providing moderate temperatures (at least 20°C) have been reached. There is a small risk that Campylobacters and Salmonellas may be present in the cooler exterior or drier parts of manure heaps, and farmers should be encouraged to compost the manure by turning to

promote higher temperatures and thorough mixing. Wetter manures (e.g. those with a low proportion of bedding or stored uncovered in wet weather) will provide less favourable conditions for composting. However pathogen survival in wetter manure heaps may be reduced by the presence of dissolved ammonia. Because of the increased shedding rates of pathogens from certain classes of stock (eg. young animals or females which have just given birth), consideration should be given where appropriate to storing their FYM separately so that it can be stored for longer time periods or composted.

Future implementation of IPPC legislation is likely to encourage the pig and poultry industries to cover heaps during storage in order to reduce ammonia emissions. Storing manures undercover will keep them drier and therefore will lead to more effective composting, higher temperatures and hence more rapid pathogen decline. Farmers should also be strongly encouraged to turn manure heaps, thereby aerating them and promoting efficient composting. A consequence of frequent turning however is increased odours and ammonia emissions as well as losses in the nitrogen content of the manure.

The majority of solid manures are stored in temporary field heaps with no insulation from the soil. Providing the MAFF guidelines for manure storage are followed, and heaps are stored on impervious bases, there should be little risk of manure-borne pathogens entering watercourses .

4.5 Effect of slurry treatment processes

4.5.1 Anaerobic digestion

4.5.1.1 Effect on pathogen levels

The effectiveness of anaerobic digestion at reducing pathogen numbers has been found to depend largely on temperatures achieved in the slurry. A study of pathogen reduction in 10 large-scale Danish Biogas plants indicated that for mesophilic systems pathogen reduction was modest (log_{10}- reduction of 1-2 units), whereas thermophilic plants were capable of achieving a log_{10}-reduction of 4 units (Bendixen 1999). Similar investigations in Germany confirmed that either a thermophilic process or pasteurisation at 70^{o}C for one hour was necessary to inactivate pathogens (Böhm *et al*. 1999). These findings mirror closely those of UK surveys on mesophilic digestion of sewage sludge where an average log_{10}-reduction of two units was observed (UKWIR 1999 a, b). A study on the inactivation of viruses in animal slurries concluded that fermentation at or above 55^{o}C was the most important factor, and that thermophilic processes were likely to kill the majority of viruses (Pesaro *et al* 1999).

4.5.1.2 Practical implications

Whilst anaerobic digestion is proven technology which has been available for 20 years, uptake has been minimal and restricted to enthusiastic farmers or those sites with specific factors, such as the need for odour control or a direct need for the biogas produced.

A study carried out in 1993 indicated that there were only 43 digesters in the UK of which 23 were definitely functional at the time. Since then, a limited number of additional digesters have been installed but significant numbers of the original 43 have fallen into poor repair. The digesters no longer in use includes the large pilot-model digester at Hanford Farms (Dorset) which supplied electricity to the National

Grid under a NFFO agreement. After 15 years use, the digester vessel failed through corrosion. There are currently between 30 and 40 plants operational on UK farms. The limited uptake is solely a consequence of the high initial cost of installation. Capital costs are currently in the order of £750/m^3 of digester capacity which equates to an expenditure of at least £60,000 to process the slurry from a 100 cow dairy herd. 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 very long and economies of scale favour large central digesters.

Under the EU 'ALTENER' programme, feasibility studies were carried out in the UK on several centralised digesters, each serving a number of farms. Around six such schemes are currently in planning, but none have yet reached the installation stage. The planned plant at Cannington in Somerset has been designed for a throughput of 200 tonnes/day of livestock slurries and other organic wastes, and will operate at mesophilic temperatures with an end-stage pasteurisation. Capital start-up costs are presently in the region of £4 million. The economics of such plants depend on the payment of gate fees for non-agricultural wastes, which will form up to 25% of the plant's throughput. Such processing plants are seen by waste disposal contractors as an avenue for the disposal of liquid organic wastes, which are being discouraged from disposal by landfill under an EU Landfill Directive. One of the principle disadvantages of centralised digestion is the logistical problems of slurry transport to the plant and post-digest transport of slurry back to farms for land spreading. In addition, there are hygiene and planning-approval concerns.

Even if anaerobic digestion could provide a complete solution to the problem of pathogens in slurry, the significant capital costs involved in equipping farms with digesters would be difficult for the livestock industry to finance given the low profitability upon which most units operate. Based on the volumes of livestock slurry produced (Pain, 1998) for individual farm scale digesters the total UK capital investment required would be c. £1,300 million for cattle slurry and £100 million for pig slurry.

4.5.2 Aerobic treatment

4.5.2.1 Effect on pathogen levels

There is some evidence to suggest that aeration of slurry decreases pathogen levels compared with non-aerated slurry. A 90% reduction in *Salmonella* numbers occurred in between 2 and 4 weeks in anaerobically stored cattle slurry. A similar reduction was achieved in less than 2 days when the slurry was aerated (Jones and Matthews 1975). Aeration also reduced the numbers of *Campylobacter* in dairy slurry (*Stanley et al*. 1998). Aeration of farm-scale slurry tanks stored in winter increased temperatures to between 19^{o}C and 40^{o}C over ambient temperature thereby reducing *Salmonella* levels by over 99% in 2-5 weeks for cattle slurry contaminated with *S. infantis*. A similar effect was observed for pig slurry contaminated with *S. typhimurium*, *Yersinia*, *Listeria*, faecal coliforms, enterococci and coliphages (Heinonen-Tanski et al. 1998).

4.5.2.2 Practical implications

It is estimated that up to 10% of pig slurry in the UK is aerobically treated, but few installations exist to treat cattle slurry. The design of aeration systems varies enormously, although most systems have 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 effective oxygenation throughout all of the stored slurry. Therefore, there is no guarantee that existing systems would achieve the conditions required to achieve effective pathogen control.

Aerobic treatment systems are expensive to install and require a high electricity input. (Williams, 1989) found the energy input required to stabilise pig slurry in an odour-free state was a minimum of 0.11kWh pig/place/day, which at a 1999 cost of 7p kW/h equates to a running cost of £3.65 pig/place/year. Adding interest, depreciation and maintenance charges to the capital costs is likely to double this to around £7-8 pig/place/year. The need for slurry mechanical separation equipment could further add

to the costs. As for anaerobic digestion, the majority of the livestock industry is excluded on a cost basis from installing effective aeration equipment.

4.6 Manure spreading

4.6.1 Slurry spreading

Slurry spreading machinery applies slurries in different ways that may affect the rate of pathogen dispersal and survival in the environment.

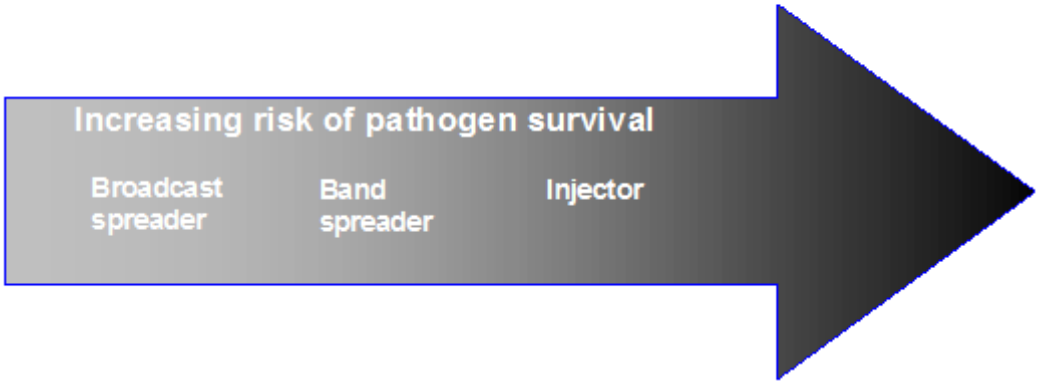
Broadcast spreading techniques are likely to generate aerosols, which are a well documented route for the dissemination of pathogens over long distances especially under windy conditions (section 4.6.1). However, if spreading is carried out in clear, sunny conditions, it is likely that UV irradiation of the slurry would occur favouring a reduction in pathogens. The current MAFF guidelines advise farmers not to spread manures in the evenings, weekends or when the wind direction is towards residential housing, and this probably provides sufficient protection against pathogen inhalation by aerosols. However, it is likely that adjacent crops, grazing land, livestock and watercourses could become contaminated by aerosol pathogens unless careful thought is given to both the method of manure spreading and the effects of current weather conditions.

Band spreaders lay trails of slurry across the soil surface and there is little risk of aerosol generation from these techniques. However, they also reduce the amount of slurry surface area compared with broadcast spreading. This means that the band spread slurry will dry less quickly and be less exposed to UV radiation increasing the potential for pathogen survival. Slurry which is injected directly into the soil is likely to retain more moisture and will be protected from UV radiation, further increasing the chances of pathogen survival, although the pathogens will be removed from the soil surface and are less likely to contaminate growing crops or be ingested by grazing animals.

A summary of the relative microbial risks from the spreading systems is shown in Figure 4. At present broadcast spreading is by far the most widely used technique for applying slurry. However, legislative pressures to reduce odour and ammonia

emissions from spreading may in future push the industry towards increased use of low trajectory techniques.

Figure 4. Risk of pathogen survival from commonly used slurry spreading techniques



Research on sewage sludge spreading found that frequent, low rate dressings were less favourable for pathogen survival than infrequent, heavy dressings, due to the pathogens being protected in the middle of the thicker layers. It is likely that the same effect would be observed with animals manures. Manure applications should not apply more than 250 kg N/ha in any one year, and based on typical nitrogen contents, beef cattle slurry would generally be applied at a higher rate (110 m^3/ha) than dairy cattle slurry (80 m^3/ha) or pig slurry (50 m^3/ha) to achieve this. This may mean that pathogens in beef cattle slurry normally survive for longer after spreading, although this assertion requires further validation.

4.6.2 Solid manure spreading

Application of FYM or poultry manures using solid manure spreaders poses some risk of pathogen dispersal. The use of flails and spinning rotors to chop and spread the waste, coupled with the height at which the manure is ejected means that there is potential for aerosols and dust generation. However, breaking up and thinly spreading

the manures will promote faster drying, and expose a greater surface area to UV radiation, thereby lowering the survival potential of any pathogens present.

To apply 250 kg N/ha from solid manures based on typical nitrogen contents, cattle FYM would generally be applied at a higher rate (42 t/ha) than pig FYM (36 t/ha), layer manure (17 t/ha) or broiler litter (9 t/ha). This may mean that pathogens in cattle FYM normally survive for longer after spreading, although again this requires validation.

4.6.3 Manure incorporation

MAFF guidelines recommend that animal manures be ploughed or otherwise incorporated into the soil as soon as possible after spreading, ideally within 4 hours, in order to reduce odours and losses of manure N as ammonia. Incorporation of manures into the soil protects against the sterilising effect of UV radiation, drying and cushions against temperature fluctuation. Consequently, rapid incorporation of manures to soil may cause pathogen numbers to decline more slowly than manures which are not incorporated. It is not clear if the depth of incorporation is likely to affect pathogen decline.

On grassland or where manures are applied to growing crops, incorporation is not possible and manures will remain on the soil or crop surface for much longer. Under these circumstances pathogen elimination is likely to proceed more rapidly.

4.6.4 Application restrictions

Pathogens are better adapted for survival in aquatic environments than in soils or crops (Thomas *et al*. 1999b), and will survive for longer periods if they are allowed entry to water courses. This is most likely to occur if manures are spread during or just before heavy rainfall, or near to surface waters and boreholes. Current MAFF guidelines suggest safe ‘no spread’ times and areas, which should reduce the possibility of this happening, providing that farmers adhere to them. The use of grass buffer strips will also reduce pathogen levels in runoff.

4.7 Survival on soils and vegetation

4.7.1 Pathogen survival in soils

(Stanley *et al.* 1998b) reported poor survival (1-20 days) of *Campylobacter* in cattle slurry applied to soil, whereas *Listeria* (section 2.3*)* and *Salmonella* (section 2.5*)* have been shown to survive for much longer periods (69-760 days). There is contradictory evidence on the length of time that *E. coli* O157 can survive in soils with estimates ranging from 7-8 days to 2 months (section 2.10.3). However, survival times have been found to depend on temperature (Maule 1999) and soil type (Fenlon *et al* 1999), with a greater chance of survival in cold conditions on impervious clay soils. In contrast a single study on *Cryptosporidium* survival found that survival was lower in winter (a few days) than in summer (2-4 weeks), although viable oocysts could be leached for at least 3 months (Svboda *et al* 1997).

Mean soil temperatures in the UK seldom exceed 15°C at a 10 cm depth, whereas average winter temperatures are around 5°C (Mawdsley *et al*. 1995). Thus pathogens in manures that are incorporated in soils may have extended survival times, as they are less likely to be subjected to temperatures high enough to eliminate them.

4.7.2 Pathogen survival on crops

Many of the environmental factors likely to influence the survival of pathogens on crops have been discussed previously. Pathogen decline on the plant surface will be enhanced by UV irradiation in bright sunshine. Similarly, the drying effects of wind and high temperatures will also help lower viability. However, rainfall heavy enough to produce splash on leaf surfaces may cause the spread of pathogens to other plants, the soil and to surface waters. Generally precipitation and high humidity will increase the time which viable pathogens are associated with vegetation (section 2.11).

In all of the cases where data is available, pathogens declined much more rapidly on the crop surface than in soil. Crops such as carrots, celery and lettuce which may be eaten raw and which may have soil particles adhering to them, therefore present a

higher risk of transmission than crops grown away from the soil surface. Although there is limited information available for pathogen proliferation on leaf surfaces, a number of pathogens commonly associated with livestock manures have been shown to exhibit biofilm growth on glass and steel surfaces of the type found in food processing plants (Gras *et al.* 1994). Biofilms are resistant to environmental stress and chemical-based antimicrobials (Hutchison and Govan 1999) and thus any pathogens which do survive long enough on the surface of leaves to form a biofilm may be difficult to inactivate during subsequent food processing.

4.7.3 Implications for survival of pathogen from spread manures

Given the relative lack of data on pathogen survival in soil and vegetation and some apparent contradictions, a precautionary approach should be taken when considering the risks of transfer to the food chain.

Where ready to eat crops (e.g. salads) are grown, the risks in terms of food safety are particularly high. Therefore, for these crops manures should never be applied directly to the growing plants and a no harvest interval of at least 6 months (i.e. there must be six months between manure spreading and crop harvest) should be observed to ensure effective pathogen destruction.

Current advice (Chambers *et al* 1999b) recommends that manures are not applied to grassland during the grazing season to minimise the risks of animal disease transmission. If this is unavoidable, farmers are advised to store manures for as long as possible before land spreading (at least one month) and to apply the manure to cut grassland rather than grazed pastures. Pastures should then be left ungrazed for at least one month (preferably 8 weeks) or until all visual signs of manure solids have disappeared. The available information on pathogen survival on vegetation suggests that the recommended intervals are long enough to ensure most pathogens are eliminated by the time grazing resumes. However, animals may also ingest soils whilst grazing and there is a chance that some pathogens may still be viable in the soil after a one month no grazing interval.

4.7.4 Implications for survival of pathogens from animal excreta on grazed land

Cattle and sheep spend a large part of the year grazing pasture land, during which time their excreta will be deposited directly onto the grazing surface. Infection or reinfection of stock grazing pastures contaminated by pathogens present in the faeces of other herd or flock members is likely, especially as animals will be in contact with fresh material. There is no practical method for prevention of stock ingesting excreted pathogens, however they will normally find excreta distasteful and will naturally avoid grazing contaminated grass**.**

Most farmers will attempt to separate obviously ill animals, a practice that should be encouraged. Where possible, when infected animals have been found in a herd or flock, uninfected livestock should be moved to fresh pastures and not returned to the original field for as long as is practicable. However, both of these practices rely on animals being visibly ill. Both sheep and cattle can harbour large numbers of zoonotic pathogens asymptomatically, making initial diagnosis of pathogen-harbouring animals difficult. Pathogens shed by grazing livestock also have the potential to contaminate surface waters, and run-off from grazed fells and farms in wet weather will contribute to the pathogen loading in groundwater, streams and rivers. This is particularly important as pathogens survive longer in an aquatic environment than in soil and on leaf surfaces .

During winter and early spring, cattle and sheep may be grazed on arable stubble crops (e.g. sugar beet tops) when conditions are likely to be cold and wet, favouring pathogen survival. Similarly, land may be used for outdoor pig farming as part of an arable crop rotation. Once the livestock have been removed and continuous re-inoculation of the soil ceases, a decline in soil pathogen numbers will follow. At present farmers are not given any guidance on minimum time intervals between livestock removal and crop harvest, but an interval of at least 6 months prior to harvest of ready to eat crops would ensure significant reductions in the numbers of pathogens present and would thus minimise the risks to food safety.

4.8 Review of existing guidance on manure storage and application to agricultural land

4.8.1 Animal manures

A full list of guidance documents is listed in Appendix I. The most important of these are the Codes of Good Agricultural Practice for the Protection of Water, Air and Soil (MAFF, 1998a,b,c) which are designed to provide practical guidance to help farmers and growers avoid causing pollution and to protect the soil. They describe the main risks of causing pollution and summarise the good agricultural practices that should be adopted to minimise these risks whilst protecting natural resources and allowing economic agriculture to continue. Much of the information in the Codes relates to management of farm manures, with the aim of preventing pollution from nutrients (nitrogen and phosphorus) or other chemicals.

Practical advice for farmers on complying with the Codes and making best use of manures is give in a series of 3 booklets entitled Managing Livestock Manures (Chambers *et al*, 1999a,b,c). A comprehensive reference book (RB209) on the use of organic manures and inorganic fertilisers is also available (MAFF, 1994).

4.8.1.1 Livestock housing

The MAFF Codes contain the following advice on managing manures to minimise ammonia and odour emissions during livestock housing:

- Wherever possible, slurry should be collected and transferred every day to a suitable store.
- Where bedding is required, enough should be used to keep livestock clean and all manure should be kept as dry as possible. Drinking systems should be managed to avoid overflow and spillage.
- Concrete areas around buildings should be kept clean and free from any build up of slurry and manure

These guidelines also promote general farm hygiene and thus will help to minimise the risks of pathogen transmission between animals. Encouraging farmers to keep solid manures as dry as possible and to provide adequate bedding is likely to promote composting and therefore pathogen elimination.

4.8.1.2 Manure storage

The Water Code provides general guidance on the design and building of slurry (and dirty water) storage facilities to minimise the risks of causing water pollution including:

- Stores should normally provide at least 4 months slurry storage capacity.
- No part of a storage facility can be within 10 m of a watercourse.

Solid manures should only be put in temporary field heaps where there is no risk of run-off polluting water. Field manure heaps should not be located within 10 m of a watercourse or field drain, or within 50 m of a spring, well or borehole that supplies water for human consumption or is to be used in dairies. Permanent stores should have a base that does not let liquid through and which slopes to allow leachate collection and containment. The Air Code recommends that natural composting is encouraged by helping air to penetrate into the heaps (by turning and use of sufficient bedding). Poultry manures should preferably be stored undercover, but if they are stored in the open, they should be in narrow "A"-shaped heaps to shed rainwater.

Water is an important vehicle for transferring pathogens from manures into the food chain either through irrigation of crops or via stock drinking. Since microorganisms will not move either through soil or across its surface more rapidly than soluble nutrients, if these guidelines are followed there should be little risk of pathogens from stored manures entering watercourses. The provision of 4 months slurry storage capacity should be sufficient to allow a significant reduction in pathogen numbers, although as stores are continually replenished, some slurry may be stored for less than this time. Slurry stores that were built before 1991 are exempt from the regulations

and may pose greater risks. Encouraging solid manures to be kept dry and aerated to promote heating by composting will also be effective in reducing pathogen numbers.

4.8.1.3 Manure spreading

In order to reduce odours and ammonia loss, the MAFF codes recommend that, wherever possible, slurry should be applied with a band spreader or injector. Manure spreading systems which minimise the production of dust or aerosols are also recommended. In addition, farmers are advised to spread manures at times when complaints and nuisance to local residents can be avoided. After surface applications of slurry and manure, the materials should be incorporated as soon as possible. These measures are likely to provide protection against pathogen inhalation, although adjacent crops, grazing land, livestock and waterways could still become contaminated. Use of band spreaders may encourage pathogen survival on the soil surface compared to broadcast spread slurries. Pathogens in injected or incorporated manures are likely to survive longer than those from surface applications, although they will be removed from contact with growing crops or grazing livestock.

Manure applications should be timed to coincide with when the crop is actively growing i.e. late winter/early spring. Where practically possible, high available N manures (slurry, poultry manures) should not be applied in autumn as this increases the risks of N loss through nitrate leaching. The Water Code specifies certain areas and times of year where manures should not be spread, in order to minimise the risks of water pollution. In Nitrate Vulnerable Zones (NVZ's) which cover around 600,000 ha of agricultural land in England and Wales (MAFF, 1999), there are closed periods (in autumn) for spreading high available N manures on sandy and shallow soils. Application rates greater than $50m^3$ or t/ha should be avoided to reduce the risk of run-off and odours, and should be reduced as necessary such that the total loading does not exceed 250 kg/ha total N. Although these guidelines would reduce the risk of pathogens entering nearby watercourses, if manures are applied in spring rather than autumn, there will be a shorter interval between application and crop harvest, and less time for soil pathogen levels to decline. However, pathogen survival rates in spring

applied manures are likely to be lower because of the increased temperature and levels of UV radiation.

It is recommended that manures are not applied to grassland during the grazing season to minimise the risks of animal disease transmission. If this is unavoidable, farmers are advised to store manures for as long as possible (at least one month) before land spreading. Pastures should not then be grazed for at least one month (preferably 8 weeks), or until all visual signs of manure solids have disappeared. These time intervals are probably sufficient to eliminate most pathogens by the time grazing resumes and minimise the transmission risks.

4.8.2 Sewage sludge

In December 1998 an agreement came into force between Water UK representing the UK Water and Sewage Operators and the British Retail Consortium (BRC) representing the major food retailers. The agreement affects all applications of sewage sludge to agricultural land and goes beyond the cropping and grazing restrictions currently contained within the DoE Code of Practice for Agricultural Use of Sewage Sludge (DoE, 1996).

The agreement takes the form of a table (the 'Safe Sludge Matrix') of crop types together with clear guidance on the minimum acceptable level of treatment for any sewage sludge (biosolids) based product which may be applied to that crop or rotation (Table 34). The agreement was driven by the desire to ensure the highest possible standards of food safety and to provide a framework which gives the retailers and Food Industry confidence that sewage sludge reuse on agricultural land is safe. The Matrix enables farmers and growers to continue to utilise the beneficial properties in sewage sludge as a valuable and cost effective source of nutrients and organic matter.

The main impacts of the Matrix are:

- the phasing out of raw or untreated sewage sludge use on agricultural land.

- the banning of surface spreading of treated sludge on grazing grassland. Treated sludge can only be applied to grazing grassland if it is deep injected.
- the requirement for more stringent treatment processes where sludge is applied to land growing vegetable crops that may be eaten raw (e.g. salad crops). Treated sludge can be applied to agricultural land which is used to grow vegetables providing that at least 12 months has elapsed between application and harvest of the crop. Where the crop is a salad which might be eaten raw, the harvest interval must be at least 30 months.
- the move towards use of mainly advanced treated sludges. Advanced treatment is used to describe treatment processes which are capable of virtually eliminating any pathogens which may be present in the original sludge.

Table 34. The ADAS Safe Sludge Matrix

Crop type	Untreated sludges	Treated sludges	Advanced treated sludges
Fruit	N	N	Y†
Salads	N	N (30 month harvest interval applies)	Y†
Vegetables	N	N (12 month harvest interval applies)	Y†
Horticulture	N	N	Y†
Combinable and animal feed crops	Y	Y	Y
Grass-grazing	N	N* (deep injected or ploughed down only)	Y*
Grass - silage	N	Y*	Y*
Maize	N	Y*	Y*

Y = All applications must comply with the Sludge (Use in Agriculture) Regulations 1989 and DoE Code of Practice (1996)
N = Applications not allowed (except where stated conditions apply)
*3 week no grazing and harvest interval applies
†10 monthe harvest interval applies

The guidelines in the Safe Sludge Matrix were designed to allay public concerns over the agricultural recycling of sewage sludge, and it would not be appropriate to apply the same guidelines to the use of animal manures. Only permitting the use of treated animal manures on agricultural land would have enormous practical and financial implications on the livestock industry in this country, because of the much greater quantities of manures involved compared with sewage sludges. Prohibiting the use of untreated manures on arable crops and grassland would result in the stockpiling of vast quantities of manures, with the subsequent risks of environmental pollution. Finding alternative 'disposal' routes (e.g. landfill) would be impossible and could not be shown to be the best practical environmental option (BPEO).

Equipping farms with slurry treatment facilities using existing technologies would be only partially effective in eliminating pathogens and prohibitively expensive. Compelling farmers to compost solid manures (the only effective treatment available) would be impractical and difficult to police. A more appropriate investment for the industry would be in more storage capacity which has benefits in terms of reduced pathogen loading and nutrient management.

Deep injection of treated sewage sludges to grassland is a feasible option as many sludges are applied by contractors who can afford to purchase state of the art injection equipment. However, most farmers still spread their own manures and use currently available broadcast spreading techniques. Also, the use of deep injection is not possible on many soils.

The harvest intervals between sludge spreading and crop harvest (12 months for vegetables and 30 months for salads) were designed so that the risk of pathogen transmission from subsequent ingestion of the crops was minimal, and take account of the human viruses often present in sludge. These intervals are longer than those that the literature suggests is necessary to reduce levels of the human pathogens present in animal manures.

4.9 Likely future developments in agricultural practice

There are some likely future development in agricultural practice or legislation which may influence pathogen levels or survival in manures.

- The introduction of IPPC (Integrated Pollution Prevention and Control) legislation to reduce ammonia emissions. This may compel pig farmers to cover slurry stores with purpose built covers and poultry farmers may be required to store manures undercover. Use of band spreaders and injectors to spread slurry will be encouraged, as will the incorporation of manures after band spreading or broadcasting. These measures are similar to those already recommended in the MAFF Codes of Practice, but they will have a legislative rather than an advisory basis. It is difficult to assess the implications of these in terms of pathogen control due to a lack of scientific data (see section 7.18)

- More farms are likely to convert to organic production as demand for organic produce continues to rise and attractive grants for conversion are available. Practices for manure management on organic farms (ie. composting and storage) are likely to decrease the chances of pathogen survival and transmission to the food chain. In addition, organic management practices may increase the native soil microbial population, which could lead to increased predation of pathogenic organisms introduced in manures. The implications of organic farming in terms of pathogen control are discussed in more detail in section 5.0.

- The use of antibiotics as growth promoters in animal feeds is almost certain to become more restricted. At present the use of some classes of antibiotics that are used for human treatments have been banned throughout the livestock feeds industry. Although this will certainly slow the spread of antibiotic resistance through bacterial populations, it may also increase livestock incidence of infectious diseases and in some cases, increase the rates of pathogen shedding.

- The demand in the UK for welfare friendly animal production practices has encouraged the widespread adoption of outdoor pig farming. Thus greater land areas in arable crop rotations are likely to have had direct inputs of pig excreta, and there is a need for recommended harvest intervals particularly where ready to eat crops are subsequently grown as part of the rotation. The move to straw- rather than slurry-based systems in the pig industry will have the effect of increasing the proportion of pig FYM, although this is unlikely to influence the risk of pathogen transfer providing the recommended management practices are followed.

5. MICROBIAL IMPLICATIONS OF ORGANIC FARMING

5.1 Certification of organic farming practices

Organic certification in the UK is mostly implemented by the Soil Association (SA) and is only awarded after strict and continued adherence to their guidelines. The SA guidelines meet the legal requirements set by the EU and the United Kingdom Register of Organic Food Standards (UKROFS; the government control body responsible for implementing the EU Regulations in the UK). This section of the report summarises the relevant parts of the SA guidelines and comments on the likely effects of organic farming practices on microbial risk. It has been written using the SA guidelines as the main information source, because the majority of UK organic farms are certified by the SA. There are few differences between the SA guidelines and the guidelines implemented by other certification bodies.

5.2 Concepts underlying organic farming

Organic farming can be defined as an agricultural practice which aims to provide environmentally-friendly and economically-sustainable methodologies for the production of food. One of the central concepts of organic farming involves taking advantage of self-regulating, ecological and biological processes in order to reduce, as far as practicable, reliance on resources external to the farm. Thus, in addition to the financial advantages for spreading animal manures as fertilisers, organic farms are obligated to strive to recycle all of their livestock manures to land. Since certification for organic farms specifically limits the use of several classes of mineral fertiliser and supplementary nutrients, there is a potential for organic farming to pose a higher risk than conventional farms that use less manures in terms of spreading zoonotic pathogens.

The tenets of organic farming include:

- Preservation and protection of long term soil fertility, including microbial flora by maintenance of organic matter levels

- Supply crop nutrients using insoluble sources, legumes and biological nitrogen fixation
- Control of weeds, diseases and pests using crop rotation, natural predation, crop and livestock diversity, organic mulching and the use of naturally resistant cultivars
- The extensive management of livestock whilst acknowledging animal welfare issues such as nutrition, housing, health, breeding and rearing
- Careful attention to minimise the effects of organic farming on the wider environment

Thus, by definition, organic farmers should take account of the impact that their farming practices have on the environment outwith the farm, and take appropriate steps to minimise any such effects.

5.3 *Organic livestock import and rearing practices*

Organic farms have strict controls on the source and living conditions of reared animals. In general, ruminants and pigs for meat production must be born and reared on an organic farm, and exceptions to this rule are made only in certain specific circumstances. Exempted animals are required to have a period of conversion of not less than 36 weeks. The only generally permitted exclusion is poultry broilers, which should be brought to an organic farm from a non-organic source before they are 1 day old.

Animals imported for milk or breeding also undergo a conversion period (36 weeks) with specific dietary requirements for the last 12 weeks. Poultry layers should be brought in before they are 16 weeks old and are subject to a 6 week conversion. Livestock brought on to an organic farm must be "adequately checked" for disease and must be accompanied by statutory records of any veterinary disease prevention treatments which have been administered. Thus, new livestock arriving on an organic farm will have an established medical history and may therefore have a lower chance of being colonised by pathogens.

5.3.1 Nutritional requirements of organically-farmed livestock

Feed for organic animals is governed by "physiological and ethical considerations", and as a consequence it may be that the quality of feed and standards of hygiene on organic farms are higher than on conventional farms. Generally, there are restrictions placed on both the source and substance of feed for organic livestock and these restrictions mainly serve to lower the chances of organic animals ingesting zoonotic pathogens in feed. Although pasture fertilisation by animal manures is encouraged, the wastes must first have been treated as described in section 5.5.

5.4 Likely levels of pathogens in organically-farmed animals

Organic livestock which are farmed according to SA guidelines, have lower housing densities, a strictly controlled diet and are regarded as having higher standards of animal care. All of these factors will tend to limit the spread of pathogens throughout livestock populations and thus organically-farmed animal manures may have a lower overall chance of harbouring zoonotic pathogens when compared with conventionally farmed animals. However, it should also be noted that organic farms are less likely to use antibiotic feed supplements or therapeutic antibiotic treatments and consequently pathogens levels in manures may be high. It is difficult to make definitive statements at present, since there is currently no data available which compares directly the pathogen prevalence in conventional and organic farming systems.

5.5 Storage and treatment of organic manures

The manures and plant residues that are permitted for application to organic land include straw, FYM, poultry manures, slurry, urine and dirty water all of which must be sourced from organic farms. In addition, sawdust and wood wastes from untreated timber, seaweed and organic processed plant residues are also permitted. Sewage sludge, effluents and sludge-based fertilisers are specifically prohibited for use as fertilisers. Under certain circumstances exemptions for the spreading of "non-

organic" animal manures to organic land may be granted by the certification committee.

Organic farms are required to have adequate storage to deal with likely generated volumes of FYM and slurry. In addition, provision in the form of extra storage should be made to enable flexibility of application timing. Thus the chances of organic farmers being forced to spread manures in unfavourable climatic conditions, or reducing the length of the storage period are lower, which in turn will reduce the risks of pathogen transfer into organic foods.

Before any of the allowed manures are applied to organic land, they are required to be "properly composted" to a temperature of 60^{o}C to facilitate the destruction of weeds, pathogens and antibiotics. During the composting process, the manure heaps should be turned, and composting should be allowed for at least 3 months. In addition, organic farmers are urged to consider a number of recommendations for the composting or storage areas. These recommendations include storage on concrete bases to contain heap leachates, composting under plastic sheeting and the lining of slurry lagoons with steel or concrete. All of these practices would enhance pathogen kill and reduce their spread from the waste during storage or composting.

There are no specific treatments that need to be applied to dirty water and slurry on organic farms. However, both of these materials are still subject to a minimum of three months storage before land application. Furthermore, the SA guidelines recommend that liquid storage facilities should be equipped with aeration facilities. Aeration is known to reduce the levels of pathogens in animal slurry (Maule 1996; Heinonen-Tanski *et al* 1998).

5.6 Spreading of organically-farmed animal manures

Spreading of animal manures on organic farms should not exceed the ability of the soil to absorb the material. Annual application loads are capped at 25 tonnes/ha, which is just under half the maximum level advised by MAFF for conventional farms. In addition, the SA have incorporated the majority of the MAFF recommendations for

manure spreading into their certification programme. Specifically, organic farmers are recommended not to spread within 10m of drainage ditches and 50m of potable water sources, and manures should not be spread on frozen soils. Thus organic farms maybe less likely to contaminate aquifer and surface waters by spreading manures containing pathogens because of the lower levels of manures applied (albeit over larger areas) and the more rigorous conformation to the codes of practice as a result of certification.

5.7 Conditions for imported manures before spreading to organic land

Unlike conventional farming, the SA supplies details of manure treatments that organic farmers must follow to keep or achieve organic certification. The guidelines which control the microbial risk of organic manures are a prohibition of heavy use of imported (from outwith the farm) manures and a statement that manures which are imported to a farm must only be from another organic farm (unless specific exemption is granted by the certification committee). Imported manures are subject to the same storage (three months) and composting restrictions as manures generated on the farm.

5.8 Microbiological risks associated with organic farms

In summary, there are a set of strict guidelines that must be adhered to by organic farmers if they wish to be certified by the Soil Association as "organic". There are specific sections of the guidelines which deal with animal health and disposal treatments for animal wastes. Although organic farmers are more reliant on animal manures as crop and grass fertilisers, likely risks associated with organic farms may well be lower than those associated with more conventional farms. Lower stocking densities and other conditions on animal health and welfare, may mean that there is less likelihood of organic animals harbouring pathogens. However, any pathogens that are present in livestock may spread more easily through an organic farm since antibiotic feed supplements and therapeutic antibiotic treatments are used less frequently.

The treatment guidelines issued by the SA before the recycling of animal manures are permitted will help lower the levels of any pathogens which are present in the manures. Organically-farmed soils may have a higher organic matter content than conventionally-managed soils, which could either support pathogens for longer periods or may encourage the growth of organisms which prey upon pathogens. Unfortunately there is currently no firm evidence to clarify this situation.

6. FARM MANURE MANAGEMENT – RISKS OF PATHOGEN TRANSFER INTO THE FOOD CHAIN

6.1 Introduction

6.1.1 Pathways for pathogen entry to the foodchain

There are many potential routes by which pathogens in animal manures could enter the human food chain. Little research has been undertaken to gain an understanding of which are the main ones but likely possibilities are:

i. Direct contamination of growing crops with manures
ii. Contamination of crops with soil where manures have previously been applied or excreta have been deposited in the field.
iii. Ingestion of contaminated grass and soil by grazing livestock following manure spreading
iv. Ingestion by grazing livestock of grass and soil contaminated by excreta deposited in the field.
v. Ingestion of contaminated fodder crops (e.g. silage) by housed livestock.
vi. Cross contamination between livestock via faeces, soil or water containing pathogens.
vii. Ingestion by livestock through contaminated drinking water.
viii. Contamination of milk from dirty udders and teats.
ix. Contamination of crops from irrigation water.
x. Contamination of livestock and crops via air, machinery and man, etc.

To undertake a risk assessment the likely most important potential routes for pathogen transfer into the foodchain have been identified as:

- Application of manures directly to growing crops. Where crops are ready-to-eat (e.g. salads) the risks in terms of food safety are particularly high.

- Livestock are grazed on land prior to growing crops where plant surface may subsequently become contaminated with soil containing pathogens. A list of crops

grown in contact with the soil is given in Table 35. The risks of human infection by soil-grown crops which are likely to be consumed raw are greatest.

- Current advice to farmers is that manures should be applied to cut grassland rather than grazed pastures. However, in both cases there is a potential risk of pathogen transmission to grazing or housed livestock, and hence to meat and dairy products.

The other potential routes of pathogen entry into the food chain are not considered at this stage in the risk assessment and it is not known how important these may be. However, once more data becomes available similar exercises should be conducted in the future for these pathways, particularly in assessing the risks of pathogen transfer where ready-to-eat crops are irrigated with contaminated water.

Table 35. Crops grown in contact with the soil

Lettuce
Radish
Onions
Beans (including runner, broad and dwarf French)
Mange tout
Cabbage
Cauliflower
Calabrese/broccoli
Courgettes
Celery
Carrots
Herbs
Garlic
Shallot
Spinach
Chicory
Asparagus
Soft fruit (e.g. strawberries)

6.1.2 Assessing the risks of pathogen entry to the foodchain

The key factors which have been used to assess the potential risk of pathogens in manures transferring into the food chain are:

1. The relative quantities of manure produced by different livestock types.
2. The prevalence and levels of pathogens in different manure types
3. Pathogen survival during manure storage
4. Pathogen survival in soils and on crops

At present, there are insufficient data available to produce a *numerical* risk assessment of pathogen transfer to the human food chain from the land application of farm manures. However, by using published data on the amounts of farm manures produced, the prevalence and levels of pathogens in farm manures, and knowledge of the effect of manure storage and survival in soils and on vegetation, it is possible to construct tables of *comparative* risks. Ultimately, the *actual* risk to human health will depend on the infective dose of the pathogens, as well as hygiene factors introduced during product processing, retailing and preparation in the kitchen.

Risk assessments are presented for each pathogen, except for *Giardia* where insufficient information was available, as tables 36 - 45. These tables represent an assessment of the risks of food poisoning pathogens in animal manures transferring into the food chain and take into account the effect of various manure management practices. Risks are represented by a number of asterisks according to the following scale.

*****	Very high risk
****	High risk
***	Medium risk
**	Low risk
*	Very low (negligible) risk

Table 36. *E. coli* O157: risks of pathogen transfer into crops grown in contact with the soil where manures have been spread previously or excreta deposited in the field.

Manure/livestock type		No storage *or* harvest restrictions	Storage >3 months	Harvest >6 months	Storage >3 months *and* harvest >6 months
Slurry	- cattle	*****	***	**	*
	- pig	**	*	*	*
FYM	- cattle	*****	***	**	*
	- pig	**	*	*	*
	- sheep	***	**	*	*
Poultry	- layer	*	*	*	*
	- litter	*	*	*	*
Dirty water	- cattle	***	**	**	*
	- pig	*	*	*	*
	- poultry	*	*	*	*
Grazing	-cattle	*****	NA	**	NA
	-sheep	****	NA	*	NA
	- outdoor pigs	**	NA	*	NA

Table 37. *E. coli* O157: risks of pathogen transfer to grazing or foraging livestock (and hence meat and dairy products) following manure spreading

Manure type		No storage *or* grazing restriction	Storage >3 months	No graze period		Forage land (grass silage/hay, maize)
				4 weeks	6 months	
Slurry	- cattle	*****	***	***	**	**
	- pig	**	*	*	*	*
FYM	- cattle	*****	***	***	**	**
	- pig	**	*	*	*	*
	- sheep	***	**	**	*	**
Poultry	- layer	*	*	*	*	*
	- litter	*	*	*	*	*
Dirty water	- cattle	****	**	***	*	*
	- pig	*	*	*	*	*
	- poultry	*	*	*	*	*

NA = not applicable

Table 38 *Salmonella*: risks of pathogen transfer into crops grown in contact with the soil where manures have been spread previously or excreta deposited in the field.

Manure/livestock type		No storage *or* harvest restrictions	Storage >3 months	Harvest >6 months	Storage >3 months *and* harvest >6 months
Slurry	- cattle	****	**	*	*
	- pig	**	*	*	*
FYM:	- cattle	****	**	*	*
	- pig	**	**	*	*
	- sheep	**	*	*	*
Poultry	- layer	***	**	**	*
	- litter	***	**	**	*
Dirty water	- cattle	***	**	*	*
	- pig	**	*	*	*
	- poultry	***	**	**	*
Grazing	-cattle	***	NA	*	NA
	-sheep	**	NA	*	NA
- outdoor pigs		***	NA	*	NA

Table 39. *Salmonella*: risks of pathogen transfer to grazing or foraging livestock (and hence meat and dairy products) following manure spreading.

Manure type		No storage *or* grazing restriction	Storage >3 months	No graze period		Forage land (grass silage/hay, maize)
				4 weeks	6 months	
Slurry	- cattle	****	**	***	*	*
	- pig	**	*	*	*	*
FYM	- cattle	****	**	***	*	*
	- pig	**	**	*	*	*
	- sheep	**	*	*	*	*
Poultry	- layer	***	**	**	*	*
	- litter	***	**	**	*	*
Dirty water	- cattle	***	**	**	*	*
	- pig	**	*	*	*	*
	- poultry	***	**	*	*	*

NA = not applicable

Table 40. *Listeria*: risks of pathogen transfer into crops grown in contact with the soil where manures have been spread previously or excreta deposited in the field.

Manure/livestock type		No storage *or* harvest restrictions	Storage >3 months	Harvest >6 months	Storage >3 months *and* harvest >6 months
Slurry	- cattle	****	**	**	*
	- pig	***	**	**	*
FYM	- cattle	****	**	**	*
	- pig	***	**	**	*
	- sheep	***	*	*	*
Poultry	- layer	***	**	**	*
	- litter	***	**	**	*
Dirty water	- cattle	****	**	**	*
	- pig	***	**	**	*
	- poultry	***	**	**	*
Grazing	-cattle	****	NA	**	NA
	-sheep	**	NA	*	NA
	- outdoor pigs	***	NA	*	NA

Table 41. *Listeria*: risks of pathogen transfer to grazing or foraging livestock (and hence meat and dairy products) following manure spreading

Manure type		No storage *or* grazing restriction	Storage >3 months	No graze period		Forage land (grass silage/hay, maize)
				4 weeks	6 months	
Slurry	- cattle	****	**	**	*	*
	- pig	***	**	**	**	*
FYM	- cattle	****	**	**	*	*
	- pig	***	**	**	*	*
	- sheep	***	*	*	*	*
Poultry	- layer	***	**	**	*	*
	- litter	***	**	**	*	*
Dirty water	- cattle	****	**	**	*	*
	- pig	***	**	**	*	*
	- poultry	***	**	**	*	*

NA = not applicable

Table 42. *Campylobacter*: risks of pathogen transfer into crops grown in contact with the soil where manures have been spread previously or excreta deposited in the field.

Manure/livestock type		No storage *or* harvest restrictions	Storage >3 months	Harvest >6 months	Storage >3 months *and* harvest >6 months
Slurry	- cattle	*****	***	**	*
	- pig	****	**	**	*
FYM	- cattle	*****	**	**	*
	- pig	****	**	**	*
	- sheep	***	**	*	*
Poultry	- layer	****	**	**	*
	- litter	****	**	**	*
Dirty water	- cattle	*****	***	**	*
	- pig	****	**	**	*
	- poultry	****	**	**	*
Grazing	-cattle	*****	NA	**	NA
	-sheep	***	NA	*	NA
	- outdoor pigs	****	NA	**	NA

Table 43. *Campylobacter*: risks of pathogen transfer to grazing or foraging livestock (and hence meat and dairy products) following manure spreading

Manure type		No storage *or* grazing restriction	Storage >3 months	No graze period		Forage land (grass silage/hay, maize)
				4 weeks	6 months	
Slurry	- cattle	*****	***	***	**	*
	- pig	****	**	***	*	*
FYM	- cattle	*****	**	***	*	*
	- pig	****	**	***	*	*
	- sheep	***	**	*	*	*
Poultry	- layer	****	**	**	**	*
	- litter	****	**	**	*	*
Dirty water	- cattle	*****	***	***	*	*
	- pig	****	**	**	*	*
	- poultry	****	**	**	*	*

NA = not applicable

Table 44. *Cryptosporidium parvum*: risks of pathogen transfer into crops grown in contact with the soil where manures have been spread previously or excreta deposited in the field.

Manure/livestock type		No storage *or* harvest restrictions	Storage >3 months	Harvest >6 months	Storage >3 months *and* harvest >6 months
Slurry	- cattle	*****	***	**	*
	- pig	***	*	*	*
FYM	- cattle	*****	***	**	*
	- pig	***	*	*	*
	- sheep	****	**	**	*
Poultry	- layer	*	*	*	*
	- litter	*	*	*	*
Dirty water	- cattle	*****	***	**	*
	- pig	***	*	*	*
	- poultry	*	*	*	*
Grazing	-cattle	*****	NA	**	NA
	-sheep	****	NA	**	NA
	- outdoor pigs	**	NA	*	NA

Table 45. *Cryptosporidium parvum*: risks of pathogen transfer to grazing or foraging livestock (and hence meat and dairy products) following manure spreading

Manure type		No storage *or* grazing restriction	Storage >3 months	No graze period		Forage land (grass silage/hay, maize)
				4 weeks	6 months	
Slurry	- cattle	*****	***	****	**	**
	- pig	***	*	**	*	*
FYM	- cattle	*****	***	****	**	**
	- pig	***	*	**	*	*
	- sheep	****	**	**	*	*
Poultry	- layer	*	*		*	*
	- litter	*	*	*	*	*
Dirty water	- cattle	*****	***	****	**	**
	- pig	***	*	**	*	*
	- poultry	*	*	*	*	*

NA = not applicable

7. FINAL CONCLUSIONS

7.1 Conclusions

These conclusions summarise the main findings of this study. Unless otherwise indicated, all data on manure quantities are annual figures and are representative for England and Wales.

7.1 Large quantities of animal manures are produced annually in the UK. These manures contain zoonotic microorganisms capable of causing foodborne illness which are recycled to food producing land thus creating the potential for human pathogens to enter the food chain.

7.2 An estimated 68 million tonnes (fresh weight) of farm manures are collected from farm buildings and yards in England and Wales. The manures are handled, stored and finally applied to approximately 30 million hectares of agricultural land. Approximately 50% are managed as solid manures and the remainder as liquid slurries. In addition, approximately 60 million tonnes are deposited directly onto grazing land used by cattle, sheep and outdoor pigs.

7.3 There is great variety in the type of manure management systems used on farms. This makes it extremely difficult to assess the risk of pathogens in animal manures and excreta entering the food chain. Therefore, the conclusions and recommendations made in this report have to be general in nature and are designed to address the main risks.

7.4 Overall, there are very few data on the levels of food poisoning microorganisms in freshly produced animal faeces. Where research has been undertaken, pathogens are usually reported in terms of their prevalence. Without knowing the initial pathogen levels it is difficult to assess the chances of them being present on the farm at the time food is harvested.

7.5 Similarly there are few data on the survival of pathogens in manures and the factors which affect survival whilst in the animal housing, during manure storage and in the soil during the period between land application and harvest of the food crop.

7.6 Collation of available data on manure production and pathogen content enables a generalised assessment to be made of the relative quantities of pathogens excreted by different types of livestock into the agricultural environment as shown in Table 46. It is important to note that Table 46 is not an assessment of pathogen transfer into food because it does not take account of pathogen die off in storage and land application.

Table 46 Collated data on fresh manure production and relative overall pathogens content

Animal Manure Type	Quantity produced (Mt) (fresh weight)	Pathogen	Pathogen prevalence[†]	Comparative total pathogen content
Cattle	73	*Salmonella*	<0.1%	Medium
		Listeria	>75%	High
		E. coli O157	16%	High
		Campylobacter	89%	Very High
		Cryptosporidium	48%	High
Pig	10	*Salmonella*	<0.1%	Very Low
		Listeria	<5%	Very Low
		E. coli O157	0.4%	Low
		Campylobacter	95%	Medium
		Cryptosporidium	<50%	Medium
Poultry	4	*Salmonella*	<0.1%	Low
		Listeria	8%	Medium
		E. coli O157	0%	Very Low
		Campylobacter	>75%	Very High
		C. parvum	<0.1%	Low
Sheep	2.6	*Salmonella*	<0.1%	Very Low
		Listeria	<35%	Low
		E. coli O157	2.2%	Medium
		Campylobacter	>75%	Very High
		Cryptosporidium	<50%	Medium

† In the absence of national UK prevalence data, localised data, or data compiled from other temperate European countries have been substituted.

7.7 There are several aspects of livestock husbandry that are known to affect the levels of pathogens excreted by animals.

7.7.1 Pathogen levels are particularly high in manures from young stock. For example, Cryptosporidium in calf manure and *Campylobacter* in lamb manure.

7.7.2 Pathogen levels are higher in the faeces of animals which have just given birth and sometimes they only appear after reproduction.

7.7.3 Stress increases pathogen levels in animal excreta.

7.7.4 Diet can have a pronounced affect on pathogen levels in several different ways.

For example:

i. Increased levels of *Listeria* in cattle excreta caused by switching from grazing to silage feeding.
ii. Increased shedding of *E. coli* O157 in cattle faeces through increasing the diet fibre content.
iii. Increased levels of shedding of *E. coli* and *Salmonella* in sheep were caused by fasting.

There is also evidence that season affects pathogen shedding, for example, levels of *E. coli* O157 in cattle faeces have been found to be higher in summer than in winter. However, such effects could also be due to different feeding systems, for example, grazing in summer and silage/compounds in winter, rather than true seasonality.

7.8 The survival of pathogens in freshly produced animal faeces will be affected by the manure management system used on a farm. In general the following assessments can be made.

7.8.1 Pathogen levels in manures that are stored in animal housing are not likely to decrease markedly. This applies to all types of manures, including straw-based animal bedding, slurry in below floor tanks and broiler litter and layer manures unless they remain there for extended periods. Therefore manures removed frequently from housing and spread onto land with no intermediate storage, which is a common practice on some farms, is likely to pose the highest risk in terms of pathogen entry into the food chain.

7.8.2 Pathogen levels in slurries will decline during storage. The rate of decline will be increased by aeration, higher ambient temperatures, low dry matter contents, high ammonia levels and extremes of pH (both high and low). Slurries with relatively high pathogen levels need to be stored for at least three months, and preferably six months, to ensure effective pathogen kill.

7.8.3 Pathogen levels in all types of solid manures will decline during storage. The most important factor affecting the rate of decline is the maximum temperature reached and the duration of heating during the composting process. The efficiency of composting is increased by a high dry matter content and frequent turning. There is a lack of information on typical heating patterns for stored manures, but properly composted manures can reach a temperature of 55-65°C over several days which will kill most, if not all, pathogens present. It is difficult to recommend a 'safe' storage time because the extent of heating is so critical in terms of killing pathogens and could be anywhere between a few days and six months. Active composting of manures likely to contain pathogens, for example from young stock, would be advisable.

7.9 Some manures are transported between farms, which creates the potential for pathogens to spread. At present no guidance or controls exist to minimise the risk of such transfer occurring.

7.10 Mesophilic anaerobic digestion appears to have a similar effect to conventional storage in terms of pathogen reduction. Thermophilic anaerobic digestion is considerably more effective because higher temperatures are achieved. However,

anaerobic digestion is not considered to be a practical on-farm control because of the high costs involved.

7.11 Aerobic treatment appears to have potential for reducing pathogen levels in slurries. A wide variety of systems exist including those which agitate and those which operate by forced aeration; the latter being more expensive. Unfortunately, there is no specific information available on whether current on-farm systems have a significant effect on pathogen reduction.

7.12 Various methods are used for applying slurry to land, ranging from surface broadcasting to injection. Obviously broadcasting will spread pathogens over large distances but in hot, dry weather pathogen kill is likely to be considerable. Injection will confine pathogens to the soil but will protect them from the sterilising effects of the UV radiation in sunlight. Overall, there is very little information available to assess the relative effects of different slurry application techniques in terms of pathogen survival and introducing pathogens from slurry into the food chain. However, it appears likely that slurry application on the surface of land as a thin layer in hot, sunny weather would be an effective means of pathogen control.

7.13 Similarly, there are various methods for applying solid manures to land but, in terms of controlling pathogen spread, surface spreading thinly in hot, sunny weather is most likely to be effective.

7.14 Once manures have been applied to agricultural land there are many potential routes by which pathogens can enter the human food chain. The most likely routes are:

i. Ingestion by livestock through grazing.
ii. Ingestion by livestock through consuming fodder crops.
iii. Cross-contamination between livestock soiled by soil/faeces containing pathogens.
iv. Ingestion by livestock through drinking water.
v. Contamination of milk from dirty udders and teats.
vi. Contamination of crops from the soil.

vii. Contamination of crops from irrigation water.
viii. Contamination of livestock and crops via air, machinery and man, etc.

The transfer of pathogens from manures into the food chain is an extremely complex and very poorly understood area. Therefore, it is impossible to assess which of the above routes are the most important and it is certain there will be considerable variation between different farms. This in turn makes it extremely difficult to accurately assess which control measures are most likely to be effective in terms of preventing pathogen transfer occurring.

7.15 Survival of pathogens in soil is affected by several factors including:

i. Neutral pH increases survival.
ii. Increasing temperature decreases survival.
iii. Freezing kills pathogens.
iv. Drying decreases survival.
v. UV radiation in sunlight rapidly kills pathogens on the surface.
vi. Natural predation.
vii. Pathogens will survive for longer in the rhizosphere.

From the information available it appears that the great majority of pathogens in manures applied to land will decline below detectable limits after three months.

7.16 The use of land, recently used for grazing, for the production of food crops presents a risk of pathogen transfer. Risks in terms of food safety are greatest where such foods are likely to be consumed raw. Currently no guidance is provided to minimise these risks.

7.17 The current guidance provided to farmers and growers on manure management in the MAFF codes of good agricultural practice are largely designed to prevent chemical contamination of water supplies. Movement of pathogens in the environment will differ from that of chemicals for a variety of reasons but it is safe to assume that in general the recommended measures will help to control pathogen spread into the

food chain. However, some of the details may need to be refined, in light of this report and once the results from current research on pathogen behaviour in animal manures becomes available.

7.18 There is minimal information on how different manure application methods affect pathogen spread and survival. In particular there is a need to compare surface spreading against soil injection and the various environmental and agricultural factors which affect pathogen behaviour and movement into livestock or onto crops. It appears likely that surface spreading of manures thinly in hot sunny weather will lead to rapid pathogen kill whereas rapid incorporation or soil injection protects from microbiocidal UV radiation.

7.19 The MAFF Water Code recommends manure application in late winter/spring as opposed to the Autumn in order to maximise nutrient utilisation. If freshly produced manures likely to contain elevated pathogen levels are applied at this time, microbial contamination of grassland and emerging crops is more likely.

7.20 Present guidance on applying manures to grassland takes account of pathogens in order to minimise the risks of animal disease transmission i.e. do not graze land for 4, and preferably 8, weeks following application. It may be necessary to revise this guidance once current research on pathogen survival on grassland is completed.

7.21 The "Safe Sludge Matrix" has been developed to minimise the risks to food safety resulting from the application of sewage sludge to agricultural land. Using the Matrix as the basis for advising farmers on how best to manage animal manures would not be appropriate for the agricultural industry. Therefore, separate guidance from that provided for the application of sewage sludge is required.

7.22 Several developments in agriculture which are likely to occur over the next few years may affect the risks of pathogen transfer into the food chain.

i) The Integrated Pollution Prevention and Control legislation may increase pathogen survival in soils by encouraging slurry injection or band spreading instead of surface broadcasting.
ii) Restrictions on the use of antibiotics in animal feeds could increase the pathogen content of animal manures.
iii) Increased adoption of outdoor pig farming could lead to greater pathogen transfer into crops subsequently planted into contaminated soils.

7.23 The number of organic farms within Britain is increasing, mainly due to financial assistance from MAFF and significant price premiums that are currently available for organic produce. Because of the rigours of the certification process in general, organic farmers are likely to adhere more closely to guidance on manure management and use than conventional farmers. When comparing organic farming practices to conventional systems there are some conflicts in terms of controlling pathogen transfer from manures into the food chain. On the one hand less use of antibiotics may well result in higher pathogen levels and prevalence in animal manures. However, better vetting of bought-in livestock, manure storage and composting and aeration of slurries, coupled with the fact that organically-farmed soils may well contain higher levels of organisms which prey upon pathogens, all support a reduction in risk. As a generalisation, it appears likely that there are lower risks of pathogen transfer from manures into the food chain on organic farms compared with conventional farms, but there is an urgent need for good scientific data to confirm this hypothesis.

7.24 The guidelines issued by MAFF regarding manure storage and spreading are more comprehensive that those issued by other countries. There is no conflict between the advice published by MAFF and that issued by the USDA.

7.25 In summary, there are a number of key areas which pose a high risk in terms of pathogen transfer from animal manures into the food chain.

i) Where animal manures are removed from animal housing and immediately applied to land.

ii) Where manures originate from young livestock and animals which have just given birth.

iii) Where manures are bought in from another farm with an unknown disease history.

iv) Manures from livestock on farms with poor disease control.

v) Land application of manures during cool, wet weather because of increased survival and transfer by surface runoff.

vi) Management of manures where the relevant Codes of Practice are not being followed. E.g. non-adherence to no-graze periods.

vii) Growing food crops on land recently used for rearing livestock or where manures have been applied recently.

viii) Livestock grazing where pathogens in fresh excreta are likely to be transferred onto fodder.

ix) Stock drinking from water contaminated with animal faeces.

x) Use of contaminated irrigation water.

7.26 A number of factors can be identified which will minimise the risks of pathogen transfer from manures into the food chain.

i) Strict adherence to all relevant codes of practice. e.g. no-graze periods and land spreading practices.

ii) Storage of manures before land application.

iii) Practical treatment of manures before land application, e.g. composting of solid manures.

iv) Land application several months before crop harvest.

v) Good livestock disease control.

vi) Importing of manures that are unlikely to contain pathogens or treatment of bought-in manures before use, e.g. by composting.

vii) Land application by surface spreading thinly in hot sunny weather.

viii) Preventing contamination of all water sources by fresh animal excreta and spread manures.

7.27 Assessing the risks of pathogen transfer into food during primary production does not necessarily equate directly to food safety as there are many other points of contamination and control measures during processing, distribution, retailing and catering. However, where produce is likely to be consumed fresh from the farm without any further processing, controls during primary production are particularly important, e.g. salad crops, pick-your-own fruit and farmhouse foods.

8. RECOMMENDATIONS

Contamination of food during primary production by zoonotic pathogens originating from animal manures is probably a contributory factor in some cases of human food-borne illness, although it is impossible at present to estimate the importance of this contribution. In order to address this issue two areas need to be tackled.

Firstly, based on current information, appropriate on-farm control measures need to be used to minimise pathogen transfer from animal manures into food. These measures must take account of the agricultural and environmental implications.

Secondly, research is needed to provide the data necessary to complete an appropriate microbiological risk assessment, following which additional controls may need to be targeted at the highest risk areas.

The following recommendations are designed to fulfil both of these objectives:

1. Consideration should be given to producing guidance documents to supplement those currently available, for example, the MAFF Codes of Good Agricultural Practice, which will take full account of the microbiological risks. It is recommended that these are based on the risk factors detailed in sections 7.25 and 7.26 of this report and in tables 36-45 and more specifically should take account of the following issues.

1.1 Where practically possible, slurries should be stored prior to land application for at least 1 month and preferably for 3 months, to provide a sufficient length of time for pathogen levels to decline. Where more than one slurry store is available on farm, these should be filled and emptied in batches, to avoid the recontamination of previously stored manures with fresh material.

1.2. Solid manures should be stored for at least 3 months prior to land spreading. Active manure management (e.g. by turning and mixing) should be encouraged to promote elevated temperatures (at least 55°C) during composting. Where this occurs

a storage period of 1 month is probably sufficient to ensure the elimination of most pathogens.

1.3. As there are increased shedding rates of some pathogens from certain classes of stock (e.g. young animals), consideration should be given to handling these manures separately and ensuring that they are stored for long periods or composted.

1.4. Farmers should be encouraged further to follow the guidelines in the MAFF Water Code on manure storage and land application practices, as this will have the additional benefit of preventing pathogens directly entering watercourses from point and diffuse pollution sources as well as reducing chemical pollution.

1.5. If farmers follow current MAFF advice on the use of low-trajectory slurry spreading techniques, this probably provides sufficient protection against the risk of direct pathogen inhalation via aerosols, although adjacent crops, grazing land, livestock and waterways could still become contaminated if there is aerosol drift.

1.6. Export of manures from the producer farm creates a potential route for pathogen spread to neighbouring land, particularly if the manure has not been stored or treated beforehand. It is recommended that recipient farmers satisfy themselves that any imported manure has been managed appropriately, and where there is doubt, to treat the manure accordingly.

1.7. We recommend that consideration is given to providing special guidance to farmers and growers using manures for the production of ready-to-eat crops (e.g. salads) because of the greater risks to food safety. Manures should never be applied directly to ready-to-eat crops and an interval of at least 6 months should be observed between manure spreading and harvest of the crop.

1.8. Where ready-to-eat crops are grown on land previously used for livestock grazing or foraging, at least 6 months should elapse before harvesting the crop.

1.9. We recommend that farmers are encouraged to follow current advice to apply manures to cut grassland rather than grazed pastures. Where application to grassland during the grazing season is unavoidable, farmers should be advised to store manures for at least one month before land spreading and to leave pastures ungrazed for at least one month or until all visual signs of manure solids have disappeared.

1.10 It is likely that stock grazing pastures contaminated by pathogens present in the faeces of other herd members will also become infected. Farmers should be encouraged to separate obviously ill animals, and where possible, the uninfected livestock should be moved to fresh pastures.

1.11 It is recommended that when livestock with an unknown disease history are brought onto a farm, where possible, their manures should be stored separately for as long as is practicable.

2. Consideration should be given to educating farmers and growers on the risks of pathogen transfer, and how these risks can be controlled. Suggested mechanisms are articles in the agricultural press; exhibits at agricultural shows and conferences, co-operation with food retailers and other organisations responsible for farm auditing; sponsorship of demonstration units at ADAS and other agricultural research centres.

3. A programme of research into pathogens in animal manures is being undertaken under MAFF programme FS35. However, completion of the projects currently underway will not provide all the necessary information. Therefore it is recommended that consideration should be given to funding research in the following areas.

3.1 Gaining a better understanding of the various mechanisms and routes by which pathogens can transfer from manures into human food, so that an appropriate risk assessment can be undertaken.

3.2 Evaluating the effectiveness of on-farm manure storage. e.g. in field heaps or slurry lagoons and tanks on pathogen survival.

3.3 Determining the effectiveness of currently used manure treatment systems, e.g. slurry aeration, in terms of reducing pathogen survival in manures.

3.4 The implications for food safety through the use of different techniques for applying slurry to land, in particular comparing surface broadcast with band spreading and soil injection.

3.5 Investigating the effects of animal husbandry and feeding practices on the faecal shedding of pathogens

3.6 Evaluating the comparative risks of pathogen transfer within organic farming systems compared with conventional farms

3.7 Confirming the hypothesis that if livestock ingest pathogens through either contaminated feeds or water that those pathogens will colonise the animals and result in their being shed in the faeces.

3.8 Gaining a better understanding of the role of water in pathogen movement on farms, in particular that used for irrigation and stock drinking.

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11. Appendix I: Guidance Documents Relating to the Recycling of Organic Wastes to Land

*** Indicates key document**

	Document name	Pages	Date	Publisher	Summary of relevant contents	Comments
	MAFF Publications					
1*	Fertiliser Recommendations for Agricultural and Horticultural Crops (RB209). 6th edition.	112	1994	HMSO	Fertiliser planning and organic manures; livestock waste production; utilisation of manures for crop production; pollution	Prepared by ADAS.
2*	Code of Good Agricultural Practice for the Protection of Water	97	1998	MAFF Publications	Information on farm waste management plans and avoiding water pollution	Contains list of relevant legislation
3*	Code of Good Agricultural Practice for the Protection of Air	78	1998	MAFF Publications	Information on farm waste treatment, minimising odours and ammonia losses	Contains list of relevant legislation
4*	Code of Good Agricultural Practice for the Protection of Soil	95	1998	MAFF Publications	Information on soil fertility, erosion and contamination	Contains list of relevant legislation
5	Water, Air and Soil Codes : Summary	7	1998	MAFF Publications	Key messages from Codes of Practice	
6	Farm Waste Management Plan : The MAFF Step by Step Guide for Farmers			MAFF		MAFF RMED
7	Controlling Soil Erosion : An Advisory Booklet for the Management of Agricultural Land	14	1997	MAFF Publications	Advice on cultivation techniques to avoid erosion. Some reference to manures as organic matter source and for mulches.	Complements advice given in the Codes of Practice.

8	Controlling Soil Erosion : A Manual for the assessment and Management of Agricultural Land at Risk of Water Erosion in Lowland England	44	1999	MAFF Publications	Good management practices to control erosion including use of organic manures	Prepared by ADAS.
9	Controlling Soil Erosion : An Advisory Leaflet for Preventing Erosion Caused by Grazing Livestock in Lowland England		1999	MAFF Publications	Preventing soil erosion and water pollution	Prepared by ADAS
10	Controlling Soil Erosion : A Field Guide for an Erosion Risk assessment for Farmers and Consultants		1999	MAFF Publications	Assessing the risk of erosion	Prepared by ADAS
11	Manure Planning in NVZs	28	1998	MAFF	Calculating land area, storage requirements and fertiliser requirements	Practical guide
12*	Guidelines for Farmers in NVZs	32	1998	MAFF	Explains NVZ rules	
13*	Managing Livestock Manures . Booklet 1 Making Better Use of Livestock Manures on Arable Land	24	1998	MAFF	How to use manures for arable crop production; calculate spreading rates; minimising nutrient losses; save on inorganic N use.	Prepared by IGER, ADAS and SRI
14*	Managing Livestock Manures . Booklet 2 Making Better Use of Livestock Manures on Grassland	24	1998	MAFF	How to use manures for grassland and forage crops; avoid sward contamination; calculate application rates; save on inorganic N use.	Prepared by IGER, ADAS and SRI
15*	Managing Livestock Manures .	24	1998	MAFF	How to select the right spreading	Prepared by IGER,

	Booklet 3 Spreading Systems for Slurries and Solid Manures				systems; prepare for spreading; organise manure sampling; calibrate spreaders.	ADAS and SRI
16	Poultry Litter Management. Action on Animal Welfare	13	1994	MAFF	Managing poultry litter to maintain animal welfare	
17	Making the Most of Manure		1999	MAFF	Guide to best practice	Flyer
18	A waste minimisation manual for farmers		1999	MAFF	Helps farmers to save money by minimising waste of all types on farms	Produced by ADAS. In press
19	MAFF Codes of Recommendation for the Welfare of Livestock.		Var-ious	MAFF	Cattle 1983 PB0074, Domestic fowls 1987 PB0076, Pigs 1983 PB 0075, Sheep 1989 PB0078, Turkeys 1987 PB0077, Goats 1989 PB0081	
20	Code of Good Upland Management PB0745		1992	MAFF	Maintaining landscape and wildlife of uplands	Probably not relevant
21	Code of Practice for the Safe Disposal of Agricultural and Horticultural Waste		1998	MAFF		
22	Preventing the spreading of plant and animal diseases - a practical guide PB0486		1991	MAFF		
23	Balance in the Countryside PB2288		1995	MAFF	Information pack on MAFF activities to conserve the countryside.	

Other literature

24*	Farm Waste Storage - Guidelines for Construction. CIRIA Report 126.	251	1992	CIRIA	Aimed at engineers/builders. Construction Industry Research and Information Association	
25*	The Control of Pollution (Silage, Slurry and Agricultural Fuel Oil) Regulations 1991 and as amended 1997 - Guidance Notes for Farmers		1997	HMSO		DoE and WOAD.
26*	EC Directive 96/61 Concerning Integrated Pollution Prevention and Control (IPPC). Implementation in the Pig and Poultry Sectors	37	1997	MAFF	A consultation paper on implementation of IPPC in the pig and poultry sectors in England. Rules on manure spreading, storage and animal housing. Legislation due to be in effect by 30 Oct 1999.	Public consultation document to be produced by theEA summer 1999
27	Buffer Strips : Good Farming Practice	14			Using buffer strips to prevent pollution, enhance farm operation and benefit wildlife	Produced by FWAG, FRPB, SAC and Rhone Poulenc
28	Understanding Buffer Strips : An Information Booklet	12	1996	EA	Some info on no-spreading zones for manures	Drafted by ADAS
29	Sugar Beet : A Growers Guide. 5th Edition	111	1995	SBREC/ MAFF	Small section on organic manure use	
30	Grass and Forage : 2. Fertiliser and Organic Manures for Grass	27	1993	DANI	Similar to ‘Managing Livestock Manures’ Booklet. Northern Ireland	Uses info from ADAS
31	Grass and Forage : 3. Grazing Management	41	1993	DANI	Managing grazing in dairy cows, beef cattle and sheep	May have implications for pathogen transfer

32	Grass and Forage : 4. Making Grass Silage	21	1993	DANI	A few words on slurry spreading on silage	
33	What's all this about Ammonia ?		1999	IGER/ADAS	Summary of the problem of ammonia in agriculture	Flyer
34	Design and Construction Guidelines for Farm Waste Storage	68	1995	SAC	Practical help for constructing farm waste stores	For Scotland
35	Bringing in Integrated Pollution Prevention and Control		1998	EA	Info on IPPC	Flyer
36	Farm pollution and how to avoid it		1998	EA		Flyer
37	Farm waste minimisation		1997	EA		Flyer
38	Farm waste regulations		1997	EA		Flyer
39	Farm waste management plans		1998	EA		Flyer
40	Regulated storage		1998	EA		Flyer
41	Managing maize the environmental way			MGA		Flyer
42	BS 5502. Part 22. Building and Structures for Agriculture, Part 22		1993		Code of Practice for design, construction and loading	
43	BS 5502. Part 31. Building and Structures for Agriculture, Part 31		1995		Guide to storage and handling of waste	
44	BS 5502. Part 33. Building and		1991		Guide to the control of odour pollution	

	Structures for Agriculture, Part 33				
45	BS 5502. Part 40. Building and Structures for Agriculture, Part 40		1990		Code of Practice for design and construction of cattle buildings
46	BS 5502. Part 41. Building and Structures for Agriculture, Part 41		1990		Code of Practice for design and construction of sheep buildings and pens
47	BS 5502. Part 50.Building and Structures for Agriculture, Part 50		1993		Code of Practice for design, construction and use of storage tanks and reception pits for livestock slurry
48	BS 5502. Part 51.Building and Structures for Agriculture, Part 51		1991		Code of Practice for design and construction of slatted, perforated and mesh floors for livestock
49	The PEPFAA Code. The Prevention of Environmental Pollution from Agricultural Activity, Code of Good Agricultural Practice	91	1992	Scottish Office	Scottish Code of Practice
50	Effluent storage on farms. HSE Guidance note GS12		1981	HSE	
51	Slurry Storage Systems.		1986	HSE	Annex to AIC 1986/155
52	United Kingdom Register of Organic Food Standards (UKROFS) - Standards for Organic Food Production				Implements the EEC Regulation for Organic Production (2092/91)
53*	Standards for Organic Food and		1998	Soil	Additional requirements for manure use

	Farming			Association Certification Ltd	on organic farms	
54	The Control of Microbial Hazards		1999	FPC	Fresh Produce Consortium - has some info of manure use on vegetables	
	Old documentation					
55	Profitable Use of Farm Manures : Farm Waste Management. Booklet 2081	22	1986	MAFF Publications		Precursor to RB209
56	Storage of Farm Manures and Slurries : Farm Waste Management. Booklet 2273	32	1984	MAFF Publications	Choosing, constructing and managing slurry stores	Superceded by Code of Practice
57	Farm Waste Management : Barrier Ditches. Booklet 2199	19	1980	MAFF Publications	Using barrier ditches to treat large volumes of dilute waste water	Superceded by Code of Practice
58	Advice on avoiding pollution from manures and other slurry wastes : Farm Waste Management. Booklet 2200	22	1986	MAFF Publications		Superceded by Code of Practice
59	Dirty Water Disposal on the Farm. Farm Waste Management Booklet 2390	31	1985	MAFF Publications	Sources and volumes; disposal systems; disposal systems	Superceded by Code of Practice
60	Farm Pollution : Dirty Water. Low rate irrigation systems. P3124	2	1988	ADAS		Superceded by Code of Practice

61	Farm Pollution : Dirty Water. Systems for Disposal. P3123	4	1988	ADAS		Superceded by Code of Practice
62	Farm Pollution : Dirty Water. Sources and Volumes. P3122	2	1988	ADAS		Superceded by Code of Practice
63	Storage of farm manures and slurries : choosing a storage system. P3042	4	1987	ADAS		Superceded by Code of Practice
64	Storage of farm manures and slurries : above ground circular slurry stores. P3043	4	1987	ADAS		Superceded by Code of Practice
65	Storage of farm manures and slurries : earth banked compounds for slurry storage. P3044	2	1987	ADAS		Superceded by Code of Practice
66	Storage of farm manures and slurries : weeping wall slurry stores. P3045	2	1987	ADAS		Superceded by Code of Practice
67	Storage of farm manures and slurries : stores for traditional farmyard manure. P3046	4	1987	ADAS		Superceded by Code of Practice
68	Storage of farm manures and slurries : effluent tanks. P3047	2	1987	ADAS		Superceded by Code of Practice
69	Code of Good Agricultural Practice		1985	MAFF /WOAD	General principles relating to manures and avoiding water pollution. Detailed info given in technical publications above.	

70	Farm Waste Management - General Information. Booklet 2077	36	1983	MAFF
71	Agricultural Smells from livestock farms. Booklet 2480	20	1986	MAFF
72	Equipment for handling farmyard manure and slurry. Booklet 2126	50	1983	MAFF

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