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Review

Pathogens in livestock waste, their potential for movement through soil and environmental pollution

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Abstract

Livestock wastes contain many pathogenic microorganisms including bacteria, viruses and protozoa. Following the application of these wastes to land the potential exists for environmental contamination. Plants, soil and ultimately water courses which may subsequently be used as catchments for public water supplies may all be affected. Research attention is now being focused on this possibility, especially in the case of protozoan pathogens which may be the most important as they are often resistant to current methods used in public water treatment. In this review we highlight some of the many factors that are likely to influence the degree of pollution by their effect on both the vertical and horizontal transport of microorganisms through soil. Soil pH, temperature, the presence of plants, microbial surface properties, type of waste, soil type and soil water content and flow may all affect the rate and extent of vertical transport, with the latter two generally considered to be the most important. Lateral movement is a particular problem in soils with impermeable substrata or in waterlogged conditions and in these cases the major factors affecting movement include rainfall rate, topography of the land and the rate at which microorganisms partition into the runoff.

Keywords: Livestock waste; Movement; Pathogens; Pollution; Soil

1. Introduction

Most farm livestock are housed for at least part of the year, and during this period, faeces, urine, bedding material and waste water is collected, either as semi-liquid slurry or solid manure. It is estimated that approximately 200 million t of waste are produced by livestock in England and Wales each year (National Rivers Authority, 1992). Cattle and sheep account for about 90% of this total with about half being voided directly onto pasture during grazing and half being collected in buildings. Although of potential value as fertiliser, these wastes pose a pollution threat due to their high biochemical oxygen demand and their ability to release nitrates and phosphates to the aqueous environment. The codes of Good Agricultural Practice for Protection of Water and Air (MAFF, 1992a,b) contain advice and recommendations to enable farmers to minimize the risk of chemical pollution. However, livestock wastes also contain large numbers of microorganisms, including many potential pathogens (Kearney et al., 1993a) and it is only recently that concern has been expressed about the possible spread of these pathogens to the human population (Fernan-

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waste type. It has been shown that organic compounds are able to compete with viruses for adsorptive sites on soil colloids (Carlson et al., 1968), and studies have shown that waste type can influence viral transport in soil. Results obtained by Dizer et al. (1984) illustrated this by showing adsorption of virus particles from a tertiary (chemically) treated wastewater effluent to be greater than that from the corresponding secondary (biologically) treated effluent. Similarly, Lo and Sproul (1977) demonstrated that extraneous organic matter competed for adsorption sites with poliovirus. They showed that not only was viral adsorption decreased but that desorption of bound virus from silicate minerals also occurred in the presence of proteinaceous material. However, contrasting results were obtained in a study by Rees (1990) investigating the movement of faecal coliforms in soil following the application of different waste types. Whilst waste type still affected the degree of microbial movement in this case it was shown that whilst bacteria were detected in the leachate of columns treated with dirty water 1–3 h after simulated rainfall, it took twice as long for them to appear in the leachate of slurry treated columns. This may have been a result of the physical retention or binding of the bacteria within the slurry matrix.

The major source of contamination on most farms is likely to be from slurry or farmyard manure. Prior to agricultural intensification, livestock were often bedded on large amounts of straw and the waste managed as farm yard manure (Jones, 1982). However, as herd

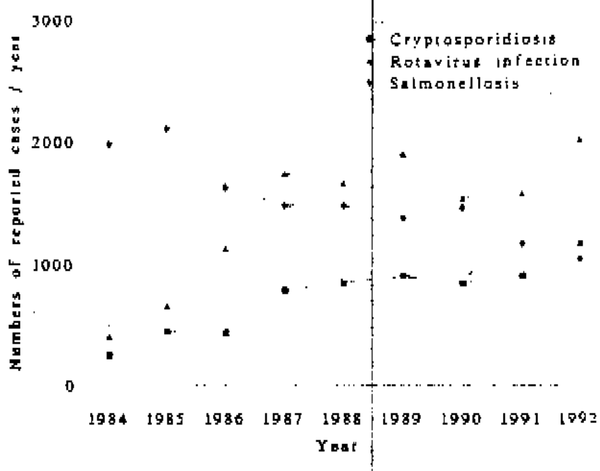

Fig. 1. UK incidence (1984–1992) of Salmonellosis, Cryptosporidiosis and rotavirus infection in cattle. Data supplied by VIDA, Central Veterinary Laboratory, Weybridge, Surrey.

size and the number of housed animals has increased there has been a move towards the collection of waste in a semi-liquid slurry form which contains only a minimum amount of solid bedding material. It is estimated that 50–60% of waste from housed cattle is now managed as slurry (Smith and Unwin, 1983). Traditionally, farm yard manure was composted, an aerobic process where temperatures often rise as high as 70°C and therefore the majority of pathogens were destroyed (Jones, 1980). However, in intensive systems slurry is collected and stored under conditions which rapidly become anaerobic and hence temperature rise and the

Table 1
Examples of pathogenic microorganisms which my be found in livestock waste (compiled from information contained in Wray (1975); Williams (1979); Reddy et al. (1981); Larsen and Munch (1986); Henry (1991); Hinton and Bale (1991) and West (1991))

Examples of pathogens found in livestock waste		
Bacteria	Viruses	Protozoa/parasites
Acremonas spp.	Coronavirus	*Cryptosporidium parvum*
Bacillus anthracis	Enterovirus	*Ostertagia* sp.
Brucella abortus	Rotavirus	*Giardia lamblia*
Escherichia coli		*Cooperia* sp.
Klebsiella spp.		
Leptospira spp.		
Listeria monocytogenes		
Mycobacterium tuberculosis		
Salmonella spp.		
Streptococcus spp. (including faecal streptococci)		
Yersinia enterocolitica		

ies are therefore required to investigate ways in which bacterial numbers may be reduced prior to the application of wastes to land (Havelaar, 1986). Chlorination of human drinking water will, generally destroy *Salmonella* spp. However, in rural areas where drinking water is supplied by wells and streams which drain off land where extensive grazing takes place, such as the uplands of Wales, hazards could still exist.

4.2. Protozoa

4.2.1. Cryptosporidium

Members of the genus *Cryptosporidium* are coccidian protozoa of the family Cryptosporidiidae, phylum Apicomplexa (Current, 1987). Although there are seven recognized species of *Cryptosporidium* the majority of research has focused on *Cryptosporidium parvum* as this species is the cause of clinical disease in man and zoonotic infections in livestock and other mammals (Robertson and Smith, 1992). Until recently cryptosporidiosis was considered rare in animals and man, and associated only with immunocompromised patients. However, research over the last decade has resulted in its recognition as an important pathogen of both animals and man. Many studies in different countries have demonstrated that *C. parvum* is detected in a large proportion of diarrhoeal outbreaks of cattle, sheep and pigs (Reynolds et al., 1986; Angus, 1990; Robert et al., 1991; Villacorta et al., 1991). In cattle and sheep cryptosporidiosis and the associated diarrhoea is almost exclusive to young animals and thus peaks of disease outbreaks occur around lambing and calving times (Fig. 2). Infection with *Cryptosporidium* often occurs in conjunction with other enteropathogens such as rotavirus, enteropathogenic *E.coli* and *Salmonella* spp., and such multiple infections increase both morbidity and mortality rates (Angus, 1990).

Infection with *Cryptosporidium* occurs following ingestion of the transmissive oocyst (4–6 μm in diameter). Oocysts are excreted in large numbers (up to 1×10^{10} g^{-1}) in the faeces of infected animals (Smith, 1992) and, since ingestion of as few as ten oocysts can result in disease, the potential for infection is huge. The severity of disease is governed by the immunological status of the host (Ungar, 1990). In man, infection may occur at any age, although due to their lower hygiene levels, incidence in pre-school children is greater than in older children and adults (Grimason et al., 1990).

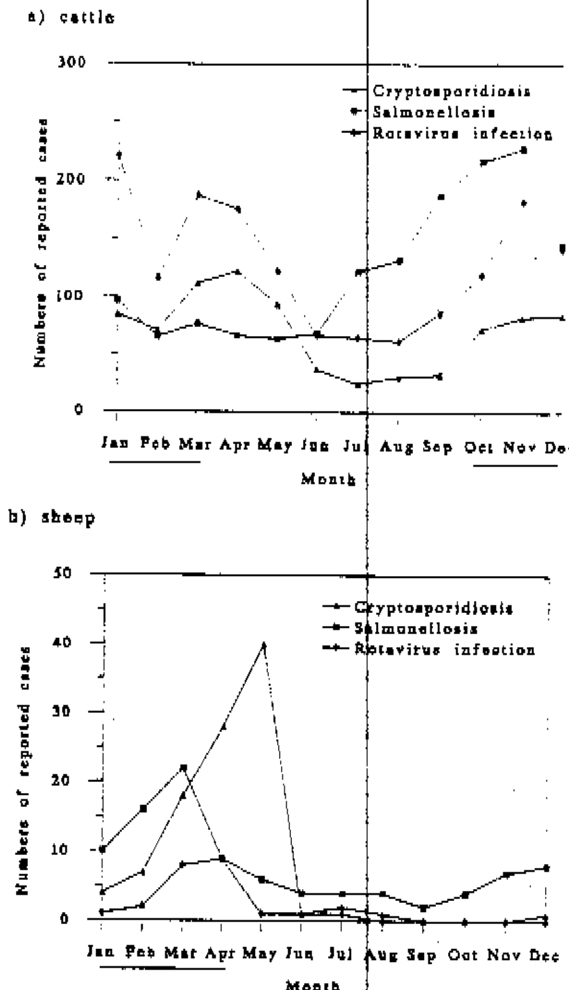

Fig. 2. Seasonal variation in the numbers of reported outbreaks of salmonellosis, cryptosporidiosis and rotavirus infection in (a) cattle and (b) sheep in the UK during 1990. Underlined months show calving and lambing times. Data supplied by VIDA, Central Veterinary Laboratory, Weybridge, Surrey.

In immunocompromised patients infection with *Cryptosporidium* is not limited to the gastrointestinal tract and both respiratory tract and biliary infections have been reported. In patients with AIDS, gastrointestinal infection with *Cryptosporidium* results in severe protracted diarrhoea and the loss of large quantities of watery faeces (Current, 1987). In such cases the diarrhoea may be irreversible and will ultimately result in death.

Infection in the immunocompetent patient is generally less severe. Symptoms include diarrhoea, abdominal pain, anorexia, vomiting, fever and flu-like

Table 2
Some factors influencing the movement of microorganisms through and across soil

Movement	Reference
Vertical	
Soil type	Bitton et al. (1974), Tan et al. (1991), Huysman and Verstraete (1993a)
Soil water content	Wong and Griffin (1976), Worrall and Roughley (1991)
Rainfall/intensity of rainfall	Wollum and Cassell (1978), Madsen and Alexander (1982), Trevors et al. (1990), Huysman and Verstraete (1993b)
Temperature	Kemp et al. (1992)
pH	Duboise et al. (1976), Burge and Enkiri (1978), Kemp et al. (1992)
Mesofaunal activity	Ruddick and Williams (1972), Opperman et al. (1987)
Surface properties of microorganism	Bitton (1975), Stenstrom (1989), Gannon et al. (1991), Huysman and Verstraete (1993c)
Presence of plant roots	Howie et al. (1987), Trevors et al. (1990), Van Elsas et al. (1991), Mawdsley and Burns (1994)
Horizontal	
Rainfall/intensity of rainfall	Evans and Owens (1992), Patni et al. (1985), Couillard and Li (1993)
Topography of land and proximity to pollutant source	Baxter-Potter and Gilliland (1988), Patni et al. (1985)
Agricultural practice	Young et al. (1980), Moore et al. (1989), Walker et al. (1990), Couillard and Li (1993)
Weather/season at time of application	Khaleel et al. (1980), Culley and Philips (1982), Baxter-Potter and Gilliland (1988)

currently appears to be the most effective technique for removing cysts from water. Ozone has been shown to have cysticidal properties in laboratory studies (Finch et al., 1993b) and hence may be of use although more data is required on the effect of factors such as treatment temperatures and water quality before an accurate picture of its reliability and feasibility in water treatment plants is achieved.

4.3. *Viruses*

4.3.1. *Rotavirus*

Rotaviruses are a relatively recently discovered group of the Reoviridae and are now recognised as one of the major causes of non-bacterial infantile diarrhoea (WHO, 1979). As with the other organisms, infection is via the faecal–oral route with up to 1×10^9 infective virions being excreted per gram of faeces (Wekerle, 1986). Infection results in symptoms ranging from subclinical to mild diarrhoea to severe and occasionally fatal dehydrating illness. Symptoms are generally most severe in infants up to 2 years of age, although adults may be infected. Malnourished and immunocompromised individuals are more susceptible to disease and in these cases mortality rates are much higher (Kapikian and Chanock, 1985).

The association between rotavirus and waterborne gastroenteritis has highlighted the need for research on both the occurrence and fate of the virus in livestock waste, and aquatic and terrestrial systems (Pancorbo et al., 1987; Ward et al., 1989). A study by Reynolds et al. (1986) of 490 calves with diarrhoea showed that rotavirus was the most frequently isolated causative agent, being responsible for > 50% of the recorded outbreaks. The number of recorded incidents of rotavirus infection in the UK in recent years is shown in Fig. 1, and it can be seen that since the mid 1980s the number of reported cases has almost doubled.

5. Factors influencing microbial movement through soil

5.1. *Vertical movement*

Unless land is saturated or of an impermeable nature, when wastes are applied vertical movement of microorganisms through the soil will occur. Despite evidence of the existence of a wide variety of pathogens in livestock waste, few studies have examined vertical or horizontal movement of these microorganisms through soil. In the absence of such information we have drawn on material accumulated in relation to comparable nonet al., 1976; Wessendorf and Lingens, 1989; Hozore and Alexander, 1991), whereas other species such as *Arthrobacter* and *Azospirillum* are relatively resistant (Labeda et al., 1976; Bashan et al., 1991). As soil pores become increasingly water filled, bacteria may find themselves in an anoxic or at least microaerophilic environment (Griffin, 1981) and for obligate aerobes this will probably result in decreased viability and survival.

Studies of both bacteria and viruses indicate increased movement in saturated soils. As matric potentials fall, water will drain from pores and hence water content together with pore size will determine the ability of microorganisms to move through soil whether by active movement or Brownian motion with results generally indicating increased movement in saturated soil (Wong and Griffin, 1976; Worrall and Roughley, 1991). Studies by Postma et al. (1989) suggest a possible explanation for this phenomenon. In their study, maximum incorporation of *Rhizobium leguminosarum* cells into soil aggregates occurred when the bacterium was inoculated into soil at low water contents. As the water content at time of inoculation increased, the numbers of cells bound in stable aggregates decreased; they hypothesized that this was due to water in pores preventing penetration by the bacteria.

In addition to soil water content, percolating water, either in the form of irrigation or rainfall will affect translocation through the soil matrix. Trevors et al. (1990) showed that in the absence of downward water flow, movement of a *Pseudomonas fluorescens* strain in soil columns was negligible, whereas following percolation the bacterium could be detected throughout the soil column and in the leachate. Similarly, Madsen and Alexander (1982) showed increased movement of both *Rhizobium* and *Pseudomonas* following percolation of soil cores.

Water flow rate, as governed by the intensity of rainfall, will also affect the rate and extent of translocation with faster flow rates increasing movement of both bacteria (Wollum and Cassel, 1978; Trevors et al., 1990; Huysman and Verstraete, 1993b) and viruses (Lance and Gerba, 1980; Lance et al., 1982). Field studies support these observations. Evans and Owens (1972) showed that the concentration of coliforms and enterococci in a subsurface drain of a field receiving pig wastes increased during high rates of drain discharge. Similarly, Patni et al. (1984) found higher concentrations of total coliforms, faecal coliforms and faecal streptococci in drainage waters from manured fields following periods of heavy rainfall.

Saturated water flow is another factor which must be considered. In this situation water flow is through large pores and channels and hence the filtering effect of soil is largely bypassed (McCoy and Hagedorn, 1979) and hence the risk of both chemical and biological pollution increased. Rahe et al. (1978) illustrated this showing rapid (1500 cm h^{-1}) transport of *E. coli* cells through saturated hillslope soils. High recovery rates indicated that once cells had entered macropores they were relatively unaffected by passage through the soil profile.

5.1.3. Surface properties

The surface properties of microorganisms may affect their association with soil particles and hence their survival and transport in soil (Huysman and Verstraete, 1993c). Hydrophobicity, cell size and properties such as the presence of cellular appendages have all been shown to affect microbial movement (Stenstrom, 1989; Gannon et al., 1991; De Mot et al., 1991). However, such properties do not act in isolation and are influenced by external factors such as the presence of cations and the organic matter content of the soil or waste.

The mobility of viruses in soil is related to the properties of the amphoteric viral protein coat (Frankenberger, 1986). It is widely accepted that viral adsorption is increased in the presence of cations, as the repulsive forces of the virus particles and soil colloids are neutralized (Bitton, 1975) and that the formation of virus-cation-clay bridges (i.e. the increase in virus adsorption) increases with increasing positive charge (Frankenberger, 1986).

5.1.4. Soil pH

Both high and low pH values are known to decrease the survival of most bacterial and viral pathogens (Hurst et al., 1980; Reddy et al., 1981) although protozoal cysts are in general considered more resistant to extremes of pH (Williams, 1979). Both the biological and physico–chemical properties of soil are affected by pH and this in turn will affect survival and transport of microorganisms. However, pH measurements of soil reflect only its bulk pH and not those of individual microenvironments. Within the soil, spatial variations in pH will influence the survival and transport of microet al., 1976; Wessendorf and Lingens, 1989; Hozore and Alexander, 1991), whereas other species such as *Arthrobacter* and *Azospirillum* are relatively resistant (Labeda et al., 1976; Bashan et al., 1991). As soil pores become increasingly water filled, bacteria may find themselves in an anoxic or at least microaerophilic environment (Griffin, 1981) and for obligate aerobes this will probably result in decreased viability and survival.

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