PATHOGENS IN ANIMAL WASTES AND THE IMPACTS OF WASTE MANAGEMENT PRACTICES ON THEIR SURVIVAL, TRANSPORT AND FATE

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Introduction

Manure and other wastes (such as respiratory secretions, urine and sloughed feathers, fur or skin) of various agricultural (livestock) animals often contain high concentrations (millions to billions per gram of wet weight feces) of human pathogens (disease-causing microorganisms). Per capita fecal production by agricultural animals such as cattle and swine far exceeds that of humans, and the trend for production facilities to harbor thousands to tens of thousands of animals in relatively small spaces results in the generation of very large quantities of concentrated fecal wastes that must be effectively managed to minimize environmental and public health risks.

Pathogens

As shown in Table 1, animal pathogens posing potential risks to human health include a variety of viruses (such as swine hepatitis E virus), bacteria (such *Salmonella* species), and parasites (such as *Cryptosporidium parvum*), some of which are endemic in commercial livestock and difficult to eradicate from both the animals and their production facilities. Hence, pathogens in animal manure and other wastes pose potential risks to human and animal health both on and off animal agriculture production facilities if the wastes are not adequately treated and contained. There are also growing public health concerns about the high concentrations of antibiotic-resistant bacteria in agricultural animals resulting from the therapeutic and growth-promotion use of antibiotics in animal production. This report reviews: (1) the types of pathogens potentially present in the manure of swine and other agricultural animals, (2) the levels of some important microbial pathogens and indicators for them that have been detected in animal wastes, (3) the potential for off-farm release or movement of pathogens present in manure and other wastes under current or proposed management practices, and (4) the extent to which these pathogens are reduced by currently used and candidate manure treatment and management technologies.

Table 1. Some Human Pathogens Potentially Present in Animal Wastes

Viruses/Groups:	Hepatitis E virus (swine), Reoviruses, Rotaviruses, Adenoviruses*, Caliciviruses*, Influenza viruses (Orthomyxoviruses)*
Bacterium/Group:	*Salmonella* spp., *Campylobacter* spp., *Escherichia coli* **, *Aeromonas hydrophila***, *Yersinia enterocolitica, Vibrio* spp., *Leptospira* spp., *Listeria* spp.
Parasites (Protozoans):	*Cryptosporidium parvum, Giardia lamblia*, and *Balantidium coli*

*Humans and animals (including swine) usually have distinct strains of these viruses, but not always.
**Some strains of these bacteria are non-pathogenic and others are pathogenic. The extent to which pathogenic strains occur in animal wastes varies with the animal species and other factors.

Some of the important pathogens potentially present in animal manures are not endemic in the United States, but there are growing concerns that such non-endemic pathogens may be introduced either accidentally or deliberately. Newly recognized or emerging livestock animal pathogens with uncertain host ranges continue to be discovered, and there are concerns that these pathogens, such as hepatitis E virus and orthomyxoviruses (influenza viruses), may be able to infect humans.

Pathways for Pathogen Movement on and off Farms

Pathogens from animal manures and other wastes have the potential to contaminate water, land and air if containment and treatment do not adequately manage the wastes. Pathogens are capable of persisting for days to weeks to months, depending on the pathogen, the medium and the environmental conditions. Many treatment and management systems for animal manure are based on the principle of no discharge and the recycling of manure constituents on the farm. However, off-farm movement or transport of animal waste pathogens has occurred via water, air and other media and is an infectious disease concern within the animal industry. Pathogen contamination of farm workers is also possible, and infection of farm workers can lead to further transmission of pathogens to family members and other contacts.

Pathogen Reductions by Manure Treatment and Management Processes

Estimated pathogen reductions in animal manures are summarized in Table 2. The reductions of some pathogens by some animal waste treatment processes have been determined in laboratory and pilot scale field studies. In general, thermophilic processes, such as pasteurization, thermophilic digestion and composting, are capable of producing extensive (>4 $\log_{10}$) pathogen inactivation, and therefore, resulting treated residuals are likely to contain only low pathogen concentrations. Further studies are recommended to better characterize pathogen inactivation in thermophilic processes for manure treatment and to define the optimum conditions to achieve extensive pathogen reductions.

Drying of some animal manures is a widely practiced management approach in some places. However, little is known about the extent to which pathogens are inactivated in manure drying processes or during dry storage because there have been few if any studies to document their effectiveness. Desiccation or drying to very low moisture levels (<1%) has been shown to result in extensive (>4 $\log_{10}$) inactivation of pathogens in municipal biosolids and in soils. Therefore, studies are recommended to determine the rate and extent of pathogen inactivation in drying and desiccation processes for animal manures.

Most mesophilic biological treatment processes for animal manures are not likely to reduce pathogen levels by more than 1-2 $\log_{10}$ or 90-99% unless several treatment reactors or processes are used in series. Therefore, treated manures, effluents or biosolids from such processes may still contain high concentrations of pathogens. The fate of these pathogens in subsequent management operations, such as land application or prolonged storage, is uncertain and has not been adequately determined. Therefore, further studies on effectiveness of mesophilic treatment processes in reducing pathogens and on the fate of pathogens in these post-treatment management processes are recommended.

Chemical treatments of animal manures are typically by lime or other alkaline treatment. Such treatment is widely practiced for municipal biosolids but less so for animal wastes. Alkaline stabilization for pathogen inactivation has been highly effective in municipal biosolids, and promising results have been obtained when it has been applied to animal biosolids. Therefore, further studies are recommended to better characterize pathogen inactivation by alkaline treatments of animal biosolids with respect to solids composition, pH and storage and handling conditions.

Summary, Conclusions and Recommendations

Pathogen reduction by animal waste treatment processes and management systems has been studied only for a few microbes, primarily indicator bacteria such as fecal coliforms. Therefore, removal and inactivation of the many different

TABLE 2. Summary of Animal Waste Treatment Processes and Estimated Pathogen Reductions

Treatment Process	Est. Pathogen Reduction (log_{10})	Comments
Physical		
Heat/Thermal Processes		
Mesophilic	Typically, 1-2	Depends on temperature, pathogen, contact time, pH, etc.
Thermophilic	Typically, >4	Depends on temperature, pathogen, contact time, pH, etc.
Freezing	Variable	Depends on pathogen, waste composition and conditions, temperature, etc.
Drying or desiccation	Typically >4 at <1% moisture; Typically <1 at >5% moisture	Depends on pathogen, contact time, pH, etc.
Gamma Irradiation	Typically >3	Varies with pathogen, dose, waste, etc.
Chemical		
High pH (>11)	Inactivation at high pH, e.g., alkaline/lime stabilization; >3-4	Varies with pathogen, contact time, pH, etc.
Low pH (<2 to <5)	Inactivation at low pH; acidification: typically, <2	Depends on pathogen, contact time, pH, etc.
Ammonia	Inactivation at higher pH where NH_3 predominates	Varies with pathogen, contact time, pH, other waste constituents
Biological Processes		
Aerobic, mesophilic	Typically 1-2	Varies with pathogen, solids separation, contact time, reactor design, temp.
Aerobic, thermophilic (composting)	Typically >4	Depends on pathogen, solids separation, contact time, reactor design, mixing methods, temperature
Anaerobic, mesophilic	Typically 1-2	Depends on pathogen, contact time, reactor design, solids separation, temperature
Anaerobic, thermophilic	Typically >4	Depends on pathogen, contact time, reactor design, solids separation, temperature
Silage treatment, mesophilic	Variable	Depends on ensiling conditions and pathogen
Land application	Highly variable and largely unknown; potentially high	Depends on site-specific factors: temperature, precipitation, vadose zone, loading, sunlight, riparian buffers, etc.

kinds of pathogens in various waste treatment processes and management systems is uncertain and needs further investigation. Although land application systems also influence pathogen survival and movement, this has not been extensively studied either. Stored manure also can attract vectors, and these vectors can either introduce or spread pathogens. Therefore, there are considerable uncertainties about the extent to which various pathogens survive waste treatment processes, are released into the environment and are available to be transported off of farms. Off-farm contamination can potentially occur inadvertently, such as in unplanned and uncontrolled releases by runoff, aerosolization or infiltration into soils and groundwater, or it can occur pur-

posefully when biosolids and other manure residuals are transported off of farms to be land applied, marketed or for other beneficial uses.

The ultimate fate of manure pathogens remains especially uncertain for large-scale, multi-stage systems employing treatment or storage followed by land application at production facilities with large numbers of animals and minimum acreage (confined or concentrated animal feeding operations). Because of the magnitude of the quantities of animal wastes generated by these facilities and the potentially high pathogen loadings that can result if the treated manure residuals still contain high pathogen concentrations, further investigation of the fate of pathogens in these systems and their surrounding environments is recommended.

Definitive or reference methods to recover and detect many of the pathogens in animal manures and their treated residual solids and liquids are lacking, especially for hyper-endemic or emerging pathogens, such as hepatitis E virus, bacteria such as *E. coli* O157:H7, *Salmonella typhimurium* and *Yersinia enterocolitica*, and parasites such as *Giardia lamblia* and *Cryptosporidium parvum*. Therefore, the extent to which these pathogens are removed, inactivated or persist in animal waste treatment processes and management systems remains uncertain due to the limitations of the recovery and detection methods. The development, evaluation and application of reliable, sensitive and affordable methods to recover and detect pathogens in animal manures and their treated residual solids and liquids are recommended.

Methods are available to recover and detect some fecal indicator microbes in animal manures and their treated residual solids and liquids. However, the methods for some indicators, such as bacterial viruses (coliphages) and spores of *Clostridium perfringens,* have not been adequately verified and collaboratively tested in these types of samples. Such verification and performance characterization studies are recommended. Also recommended are comparative studies on the removal, inactivation and fate of indicator microbes and animal pathogens in manure treatment processes and management systems. If such studies show that indicator microbes reliably reflect or predict the responses and fates of animal pathogens in manure treatment processes and management systems, then the indicators can be used in practical, rapid and affordable monitoring and surveillance activities to assess treatment process and system performance and the pathogen quality of treated residuals.

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