AMERICAN SOCIETY FOR MICROBIOLOGY

Land Application of Organic Residuals: Public Health Threat or Environmental Benefit?

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AMERICAN SOCIETY FOR MICROBIOLOGY

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This booklet is the result of a workshop held in Washington, DC to discuss microbiological concerns about land spreading, the appropriate disposal of biosolids and the role of microbiology.

The committee was made up of scientists with expertise in environmental and agricultural microbiology.

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On the *Cover*:
E. coli bacteria, shown in an undated picture at the Helmholtz Center for Infection Research in Brunswick, Germany. © *Reuters*

TABLE OF CONTENTS

I. INTRODUCTION

All living organisms produce wastes that are unwanted or seem to be unusable. These wastes encompass a wide variety of materials, both organic and inorganic. Some receive little attention at all. Others, such as sewage, are highly regulated by local, state and federal governments to safeguard human and environmental health. Still others are deemed "natural" and organic, like animal manures.

While certain wastes appear to have little or no intrinsic value, the concept "one person's garbage is another's treasure" animates the large and growing practices of waste reclamation and recycling. Aluminum, glass, plastics and paper of all kinds are among the many wastes currently recycled for profit. Even sewage and manures have been recognized as valuable sources of soil nutrients and energy production.

The growing emphasis on sustainability has also promoted increased interest in reuse and recycling. In some cases this has resulted in novel approaches for energy generation, such as electricity production from 'biogas' formed during organic waste treatment. It has also sparked renewed interest in time old practices like spreading manure as fertilizer. In this context, many wastes are no longer unwanted or unusable, but represent raw materials for new products.

The benefits of waste recycling, however, are not always obvious and can be accompanied by considerable concern and controversy. Use of **organic residuals** represents one such case. Organic residuals include various animal manures from meat, poultry and dairy industries; food and other plant materials in municipal solid wastes; and **biosolids**, the organic residuals produced during municipal wastewater treatment.

In this document, we review the diverse types of organic residuals; how such residuals are produced, used and regulated; and the associated microbiological issues. We summarize science based observations pertinent to decision making for organic residuals use, identify gaps in knowledge that need to be addressed, and offer recommendations to improve the knowledge base essential for safe and sustainable management of organic residuals.

II. WHAT ARE ORGANIC RESIDUALS, WHERE DO THEY COME FROM, HOW MUCH ARE THERE?

The term "organic residuals" includes several different waste categories. Among them are the organic fraction of municipal solid waste, animal wastes or manure, and biosolids that comprise the organic solids remaining after sewage treatment.

In the United States, approximately 1,100 pounds of organic municipal solid waste are produced on average per person per year, which includes approximately 200 pounds wet or 100 pounds dry food and yard waste (leaves, grass, limbs and other plant debris). In contrast, farm animal manure production is approximately 1000 lbs dry weight or 5000 pounds wet weight per person per year, most of which originates from the roughly 450,000 animal feeding operations (AFOs) that collectively produce over 100 million dry tons of manure per year (Table 1; Burkholder et al., 2007).

Compared to organic residuals from municipal solid waste and manure from AFOs, approximately16,000 municipal wastewater treatment plants operating in the U.S. produce a relatively small 5.6 million tons of biosolids annually, or about 40 pounds dry (120 wet pounds) mass per person on average (Table 1; National Research Council, 2002). Though biosolids represent only a small fraction of total annual organic residuals produced, they are the most processed, most regulated, most studied and most controversial with respect to disposal and possible beneficial uses. The heightened attention to biosolids derives primarily from concerns about the presence of microbial pathogens (Table 3) and chemical contaminants.

Chicken litter application via a spreader in Mississippi

III. HOW ARE ORGANIC RESIDUALS USED BENEFICIALLY?

Land application of organic residuals offers a significant option for beneficial use that is currently widely employed. However, there is a potential to expand land application. For example, animal manures are applied to only 10% of all available agricultural land, and only about 0.1% of available agricultural land is spread with biosolids. Land use for residuals varies widely on a local to regional basis and is also influenced by the distance from centers of biosolids production.

Animal wastes and manures have been used as fertilizer for agricultural crops since before the Roman Empire. Similarly, human wastes or "night soil" have been utilized as fertilizer in China for thousands of years, and in the United States for more than 150 years. A recent report estimates that about 200 million farmers worldwide grow crops in fields fertilized with human waste (IWMI, 2010). Organic residuals clearly can be beneficial, fulfilling goals for sustainability that follow "**triple bottom line**" accounting, which considers economic, societal and environmental benefits.

Economic benefits of land application depend on the balance between conventional organic residual disposal costs (landfill tip fees and transport costs) and potential revenues associated with the value of the material in the broader market. Materials may need additional processing before they are suitable for beneficial use, resulting in higher costs to the producer. Treating material to reduce or eliminate pathogens, for example, will affect costs associated with beneficial uses. Regulatory requirements for managing materials may also figure into the cost benefit balance.

In some cases, economic incentives may be available to encourage alternative uses. Carbon credits for food scraps diverted from landfills to anaerobic digestion facilities or composting operations can help offset treatment costs. Similar credits might follow from increased carbon sequestration in soils accompanying land applied organic residuals.

Table 1. Quantities of select organic residuals generated annually (million tons) in the United States, approximate percentage applied to land, and summary of regulations governing beneficial uses of each material. Quantities are given on a dry weight basis unless otherwise specified.
(MSW = municipal solid waste)

Material	Amount	Land applied (%)	Regulations
Biosolids	5.6	60	Federal, state and local regulations; limits for contaminant levels; pre-treatment regulations; pathogen regulations
Manure	133	95	Best management practices; some limits on direct discharge into water bodies for AFOs
MSW total	236 (Wet)	-	Federal, state and local regulations for landfill operations
MSW organic	150 (Wet)	-	Federal, state and local regulations for landfill operations
Food waste	10	2	Materials that are composted must meet pathogen reduction requirements in some states
Yard waste	15	65	Materials that are composted must meet pathogen reduction requirements in some states

To optimize economic benefits, the viability of all end use options must be factored into decision making processes. Land application of organic residuals may only be feasible if certain economic incentives are instituted. These incentives may evolve as a result of a fuller understanding of the benefits of reusing organic residuals.

Societal benefits of organic residuals land application derive from the development of sustainable agroecosystems that better integrate wastes as resources for food, fiber and biofuel production. In this context, land application of organic residuals is one component of a set of "green" practices and technologies. Development of sustainable agroecosystems, to which land application can contribute, has become a priority as concerns about long term energy availability and climate change grow.

Societal costs of organic residuals land application derive from risks (or the perception of risks) for human and environmental health. Health risks can result from the presence of toxic chemicals and from microbial pathogens. Contrary to public perception, Class A biosolids contain no detectable microbial pathogens and pose no risk to human health from microbial pathogens. In contrast, Class B biosolids and manure both contain microbial pathogens, but appropriate management of substantially reduces risk (see glossary). New management strategies may reduce risks for other organic residuals, while better communication of risks versus benefits could increase public acceptance.

Environmental benefits and costs constitute a major factor in determining best management practices for organic residuals, including land application. When used within existing guidelines, land application of organic residuals offers multiple environmental benefits that can be incorporated into sustainable practices. These include reduced need for fossil fuel dependent fertilizers, increased soil carbon sequestration, improved soil tilth and plant productivity, and reduced use of energy-dependent incineration or expensive landfills for residuals disposal. A greenhouse gas balance for different end use and disposal options for municipal biosolids is shown below.

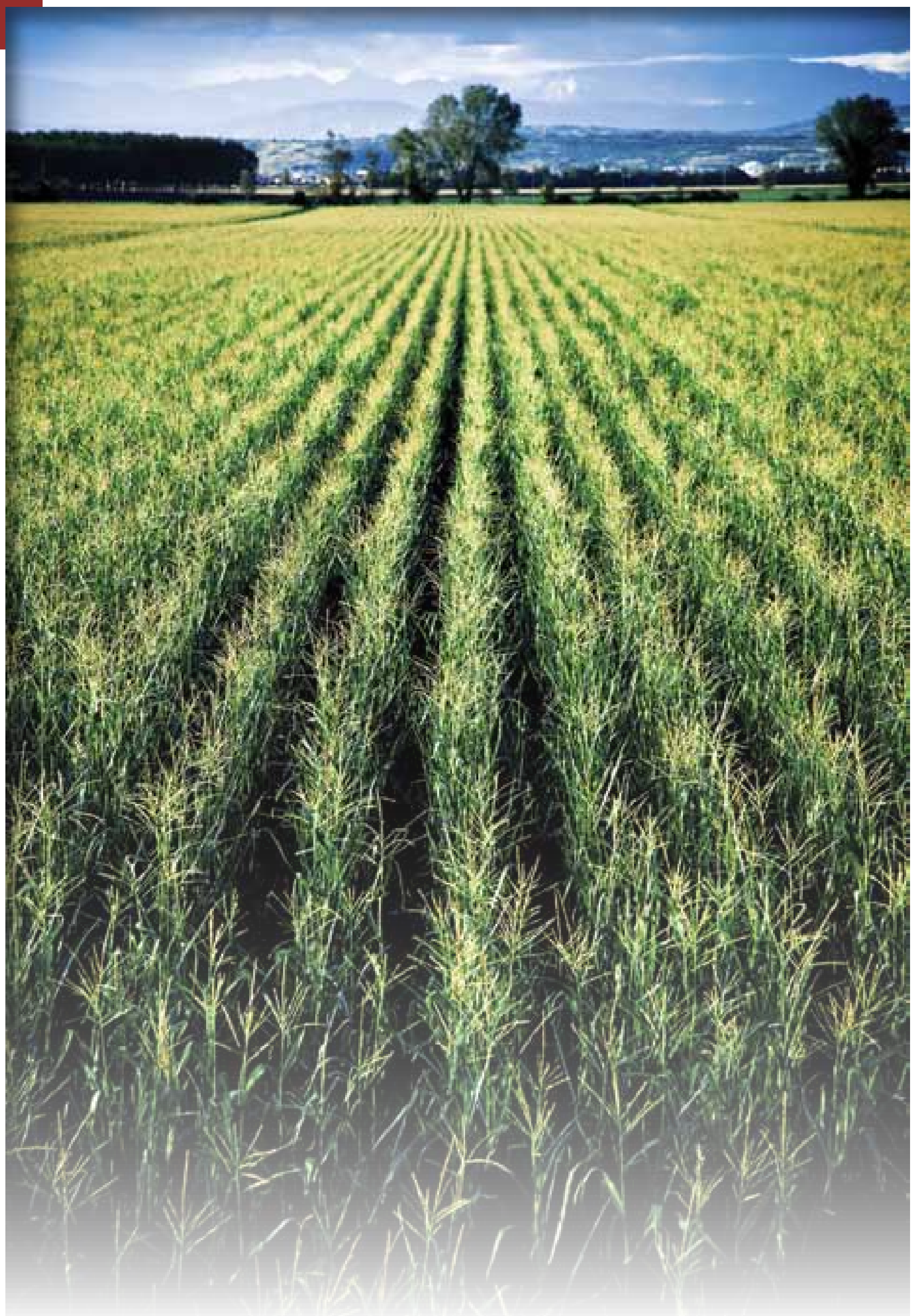
Table 2. Greenhouse gas mass balance for municipal biosolids disposal via land application or incineration. All values are milligrams of CO2 equivalent gases per milligram of biosolids disposed.

Land application		Incineration	
Variable	**CO_2 equiv**	**Variable**	**CO_2 equiv**
Anaerobic Digestion	-0.3	Added energy	0.2
Fertilizer Avoidance	-0.27	N_2O emissions	1.6
Soil Carbon Sequestration	-0.26		
Total	**-0.83**		**1.8**

Source: Canadian Council Ministers on the Environment, http://www.ccme.ca/ourwork/waste.html?category_id=137

Environmental costs can accrue from inappropriate uses of organic residuals, including over application and applications near open waters without appropriate buffers. Both actions can contaminate surface and groundwater with excess nutrients, pathogens and **endocrine disrupting compounds**. Improperly managed animal manure lagoons can also overflow, resulting in large scale contamination of fresh waters. Greenhouse gas emissions from manure lagoons are major methane sources, and land applied organic residuals can lead to production of the potent greenhouse gas, nitrous oxide (N_2O).

In summary, there is considerable potential for beneficial use of organic residuals through land applications. These beneficial uses can contribute to sustainable agricultural production and support a triple bottom line with positive economic, societal and environmental outcomes. Land application of organic residuals is not without risks or costs, however, and these must be carefully evaluated and managed through objective and comprehensive scientific analyses that fully inform policy decisions.



IV. WHAT ARE THE RISKS FROM LAND APPLICATION OF ORGANIC RESIDUALS? WHAT ARE THE KNOWLEDGE GAPS?

BIOLOGICAL RISKS

Over the past decade, the presence of pathogens in organic residuals has persisted as one of the primary issues debated by advocates and critics of land application. Pathogens unique to animal manures or biosolids and those common to both are shown in Figure 1. Although biosolids and animal manures share some bacterial pathogens, viruses, such as members of the enterovirus group (enterovirus, coxsackievirus, poliovirus and echovirus), adenovirus, and norovirus, are exclusive to Class B biosolids. Class B biosolids therefore are more likely to harbor higher levels of human viruses, whereas animal manures are more likely to contain higher levels of pathogenic bacteria.

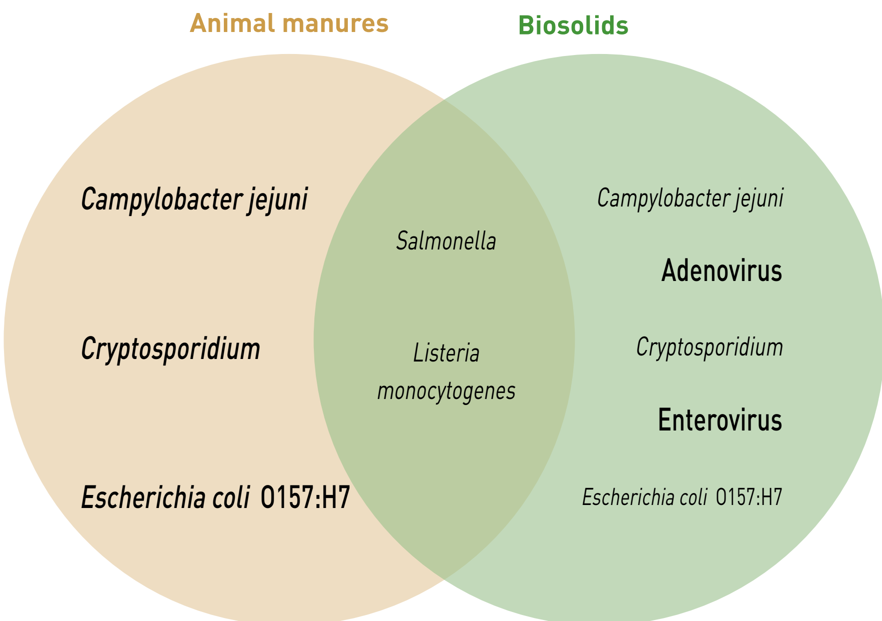


Figure 1. Relative occurrence of pathogens in untreated animal manures and biosolids. Font size indicates frequency of detection. Pathogens in area of overlap occur in both types of residuals. Adenovirus and enterovirus occur only in biosolids.

Animal manures and biosolids can be treated to reduce or eliminate disease causing microbes prior to land application. For example, biosolids are physically, chemically and biologically treated to reduce pathogens to levels specified for Class A and B designations (Tables 3 and 4).

Regulations established and administered by the U.S. Environmental Protection Agency (Part 503 rule, 1993) also reduce adverse human health impacts of biosolids. Regulations for land application of Class B biosolids limit human exposure to pathogens by delaying harvesting post application, and by minimizing public encroachment on lands with applied biosolids through site restrictions (National Research Council, 2002).

Table 3. Standards for Class A and B biosolids (from Part 503 Pathogen Density Limits, USEPA, 1993). Values are in most probable number, colony- or plaque-forming units (MPN, CFU and PFU, respectively). In principle, each unit represents a single organism or virus. Standards for Class A biosolids can be met based on numbers of *Salmonella* or combined standards for fecal coliforms, enteric viruses and viable helminth ova.

Pathogen or Indicator	Standard Density Limits (dry wt.)
CLASS A	
Salmonella	< 3 per 4 g TS (MPN) or
Fecal coliforms	< 1000 (MPN) per g TS *and*
Enteric viruses	<1 per 4g TS (PFU) *and*
Viable helminth ova	<1 per 4g TS (ova)
CLASS B	
Fecal coliform density	< 2,000,000 (MPN or CFU) (Geometric Mean)

In contrast, relatively few regulations govern land applications of manure. There are no rules related to pathogen levels, yet animal manures may contain pathogens such as *Campylobacter* spp., *Escherichia coli*, *Salmonella* spp., *Listeria monocytogenes*, *Cryptosporidium parvum*, and *Giardia lamblia*, and hepatitis E depending on the manure source (Guan and Holley, 2003; Hutchinson et al., 2005; Table 4).

Pathogens found in animal manures or in surface water runoff carrying manure material have been implicated in some of the largest public health challenges in recent years (Curriero et al., 2001; Hrudey et al., 2003). Disease outbreaks in California (Salinas Valley), Wisconsin (Milwaukee), and Canada (Walkerton, Ontario) were attributed to *E. coli* O157:H7 from animal manure, *C. parvum* from contaminated food crops, and *E. coli* O157:H7 and *Campylobacter* contaminated drinking water, respectively (Hoxie et al., 1997; Hrudey et al., 2003; USFDA, 2006). In all three cases, water runoff and feral animals as carriers from nearby manure point and non-point sources were identified as likely contamination sources.

Risks from pathogens in animal manures are typically controlled through "best management practices" (BMPs), which are not regulations per se (USDA-AMS, 2000). Moreover, BMPs for manure application are typically based on crop nutrient needs and limiting nutrient runoff, not health concerns (Pote et al., 2003). Manure is rarely applied to land intended for food crops that are traditionally eaten raw, but the unintentional contamination with manure derived pathogens still occurs periodically.

In certain cases, management practices effectively reduce pathogen content prior to land application. For example, some animal manures are stored prior to use and extended storage can inactivate certain pathogens. Both manures and biosolids are sometimes composted and then land applied. In general, technologies used to reduce or eliminate pathogens in municipal biosolids can be used to reduce pathogen loads in animal manures. For example, manures can be digested for energy production prior to land application (National Research Council, 2002; Burkholder et al., 2007).

Table 4. Approximate concentrations of pathogens in Class B biosolids and animal manures. Values are in colony- or plaque-forming units (CFU and PFU, respectively).

Organism	Source	CFU or PFU g^{-1}	Reference
BACTERIA			
Campylobacter jejuni	Manure[1,2]	1400	Kelley et al., 1995; Chinivasagam et al., 2004; Hutchinson et al., 2005; McLaughlin et al., 2009
	Biosolids	2	Jones et al., 1990
E. coli O157:H7	Manure[1,2]	110	Berry et al., 2005; Hutchinson et al., 2005
	Biosolids	<1	Pepper et al., 2010
Listeria monocytogenes	Manure[1,2]	210	Hutchinson et al., 2005; McLaughlin et al., 2009
	Biosolids	20	Garrec et al., 2003
Salmonella	Manure[1,2]	180	Chinivasagam et al., 2004; Hutchinson et al., 2005; McLaughlin et al., 2009
	Biosolids	50	Zaleski et al., 2005; Gerba et al., 2008; Pepper et al., 2010
VIRUSES			
Adenoviruses	Biosolids	20	Pepper et al., 2010
Enteroviruses	Biosolids	<1 to 30	Soares et al., 1994; Guzman et al., 2007; Lang et al., 2007; Pepper et al., 2010
PARASITES			
Cryptosporidium	Manure[1,2]	3	Hutchinson et al., 2005
	Biosolids	2	Guzman et al., 2007

[1] Mean concentration of pathogen in multiple manure types and sources.

[2] Hutchinson et al., 2005 reported mean values were weighted to account for negative values.

Food and yard wastes can also pose risks from pathogens. For these wastes, pathogen concentrations vary based on the source of materials and time of year. Yard wastes are often contaminated with fecal material from pets, for instance. Food wastes can contain pathogens, but concentrations are likely to be significantly lower than in wastes containing fecal material.

Routes of exposure

Potential pathways for exposure to pathogens in organic residuals include direct exposure through physical contact with either stored residuals or after mixing with soil. Exposure can also be indirect via transport of pathogens as bioaerosols to off site communities. Consumption of groundwater or food contaminated with pathogens following land application may also result in infections. Risks from pathogens are essentially a function of pathogen concentration in the residuals combined with the magnitude or extent of exposure. Risks associated with these different pathways have been quantified (Table 5).

Table 5. Occupational risks associated with direct contact[1, 2] of pathogens within animal manures and biosolids[3,] presented as chance of infection per exposure event (Brooks et al., 2009). (NA = nonapplicable, as there is no data to suggest pathogen's presence in the residual).

Pathogen	Daily Risk (per 1000)			
	Cattle or Cow Manure	Poultry Manure	Swine Manure	Class B[5] Biosolids
Campylobacter jejuni	≤ 900	≤ 4000	≤ 4000	≤ 50
E.coli O157:H7	≤ 1	NA	NA	NA
Listeria monocytogenes	≤ 2	≤ 0.6	≤ 1	≤ 0.09
Salmonella	≤ 30	≤ 40	≤ 10	≤ 8
Cryptosporidium	≤ 20	NA	NA	≤ 20
Adenovirus	NA	NA	NA	≤ 7000
Coxsackievirus	NA	NA	NA	≤ 500

[1] Assumes worker direct contact and ingestion occurs with fresh residuals during an 8-hour work day and no attenuation period.

[2] Occupational risk assumes no personal protective equipment.

[3] Class A biosolids' risks are assumed to be negligible due to the absence of detectable microbial pathogens in Class A biosolids.

Table 6. Community risks of infection associated with indirect pathogen contact from three indirect exposure scenarios from animal manures and biosolids that are transported off-site[1, 2, 3] following land application of the residual. Data presented as chance of infection per exposure (NA = nonapplicable, as there is no data to suggest pathogen's presence in the residual).

	Risks from single indirect exposures to manures or biosolids (per 10,000)			
Pathogen	Cattle or Cow Manure	Poultry Manure	Swine Manure	Class B[4] Biosolids
Campylobacter jejuni	≤ 0.0002	≤ 0.008	≤ 0.009	≤ 0.00001
E.coli O157:H7	≤ 0.00001	NA	NA	NA
Listeria monocytogenes	≤ 0.00001	≤ 0.00001	≤ 0.00001	≤ 0.00001
Salmonella	≤ 0.00001	≤ 0.00001	≤ 0.00001	≤ 0.00001
Cryptosporidium	≤ 0.00001	NA	NA	≤ 0.00001
Adenovirus	NA	NA	NA	≤ 0.002
Coxsackievirus	NA	NA	NA	≤ 0.00009

1 Assumes 292 g food-crop consumed on a one-time exposure from plots amended with residuals and food-crop harvested four months after residual land application.

2 Assumes runoff transport of residual-borne pathogens to an adjacent food-crop field and subsequent crop ingestion.

3 Assumes aerosol risks during land application of the residual to a population located 100 m downwind of the site and 10% ingestion of inhaled aerosols.

4 Class A biosolids are assumed to be pathogen free and hence risks are below those presented above for Class B biosolids.

A. Occupational risk

Occupational risks to personnel working with animal manures or Class B biosolids in the field on a daily basis are shown in Table 5. Daily risks from pathogens associated with animal manures range from 1 infection per 2 exposures to less than 1 infection per 10,000 exposures; these risk levels indicate that the possibility of infection from *C. jejuni* warrants attention. Likewise, the risks from organisms unique to biosolids are significant in the case of adenovirus. When risks from pathogens associated with both residuals are compared, overall risks are frequently greater for animal manures (*Listeria, Salmonella* and *Cryptosporidium*) than biosolids. When calculating occupational risks, the assumption is made that 1 gram of the residual is accidently contacted, subsequently ingested, and that no attenuation period occurs between land application and the exposure event.

B. Community risks

Community risks are all risks from pathogens that occur off-site. These include pathogens in bioaerosols that are transported off site and contamination of food due to run off with contaminated water, i.e. indirect pathogen contact. Table 6 presents risks that can occur from all indirect routes of exposure.

i. Bioaerosols

In general, the calculated risks for bioaerosols are below 1 per million chance of infection, regardless of the pathogen. The exposure is assumed to take place at 100 meters downwind of the site during the land application of the residual, lasting one hour in duration. These are conservative assumptions for community exposures.

ii. Contamination of food or water

Class A biosolids have minimal risk associated with use on edible food crops as a result of prior treatment that eliminates pathogens. Regulations prohibit the use of Class B biosolids on food crops eaten directly, that have direct contact with soils, or can be eaten directly without processing. Rather, Class B materials are normally applied to wheat, field corn and other field crops, including pasture grasses. Animal manures are not normally used to fertilize vegetable crops, but fresh animal manures can contaminate crop fields due to excessive rainfall. The risk of infection dramatically increases in such scenarios, as evidenced by several outbreaks of foodborne disease associated with *E. coli*. Similar scenarios can occur with Class B biosolids; risks for proper residual land application senarios have been simulated and are presented in Table 6.

Community risks associated with indirect contacts with manure and Class B biosolids are typically below 1 per billion chance of infection in a one time exposure scenario, and pale in comparison with occupational risks.

C. Other biological risks

Other biological concerns associated with land application of residuals include antibiotic resistant bacteria, **prions** and aerosolized **endotoxin**. For example, prophylactic dosing of antibiotics in AFOs results in relatively high concentrations of antibiotic resistant bacteria in animal manures compared to biosolids (Chee-Stanford et al., 2009). The presence of antibiotics and antibiotic resistant bacteria in organic residuals is well documented, but risks from antibiotic resistant bacteria in soil amended with residuals are thought to be low (Brooks et al., 2007). In this context it is important to note that soils are the original source of natural antibiotics and that all soils contain antibiotic-resistant bacteria.

Risks from exposure to prions (the causative agents of bovine spongiform encephalopathy or BSE) associated with biosolids are not well known. Takizawa (2009) documented rapid inactivation of prions in biosolids incubated at mesophilic (30°C) and thermophilic (50°C) temperatures associated with wastewater treatment processes, which suggests that risks are low. Environmental transmission of prions via land application of manures is also considered very low (Gale, 1998), but lack of manure treatment prior to land application limits the potential for prion destruction.

The majority of endotoxin aerosolized from land-applied residuals originates from soil during agricultural operations (*e.g.,* tilling) rather than from the residuals themselves (Brooks et al., 2006).

CHEMICAL RISKS

Historically, metals and organic chemicals associated with animal manures and biosolids have been worrisome, but point source controls have decreased concentrations of many such contaminants in sewage, thus reducing the need for concern.

Excessive nitrate and phosphate concentrations associated with manure and biosolids are also a concern because of their potential to pollute surface and groundwaters. Current application rates of biosolids are largely based on crop nitrogen demand and are restricted to rates that limit the potential for nitrate contamination of surface and ground waters. Manure applications are limited by best management practice guidelines, also largely based on nitrogen demand considerations. Phosphorus considerations, however, may ultimately limit residual loading rates. Phosphorous **eutrophication** of estuaries along the east coast of the United States linked to animal manures continues to be a high profile problem, but phosphorous related issues threaten land application of residuals in several areas where sensitive water bodies exist. Applying residuals to land based on crop phosphorous demands, or to meet exceptionally low maximum contaminant levels for phosphorous, could dictate such low application rates that land application may be uneconomical and impractical (Elliott & O'Connor, 2009).

At present, the concentrations, distribution and effects of endocrine disruptors dominate concerns about chemical risks. Endocrine disruptors include pharmaceuticals, personal care products and flame retardants associated with biosolids, and estrogenic steroidal hormones and veterinary pharmaceuticals associated with animal manures. Risks to humans from endocrine disruptors within land applied residuals are unknown but thought to be low. Risks from polybrominated diphenyl ethers (PBDEs) and estrogenic compounds contained within land applied biosolids were recently evaluated (Quanrud et al., 2010) and found to be low. Instead, the primary risks to human health associated with these compounds are related to direct household exposure from dust. Concentrations of PBDEs, for example, are much greater in household dust than in municipal biosolids (Johnson-Restrepo & Kannan, 2009). Many studies have reported the serious adverse effects of endocrines, including hormone mimics, on the environment. Clearly, the issue of endocrine exposure is one area where more research is needed, but it is not evident that land application of residuals is a major source of such exposure.

Much is known about land application of organic residuals, but few comprehensive studies of the long term consequences have been conducted. Many studies focus on narrow aspects of land application (*e.g.,* soil fertility or quality), or are limited in the number and kinds of residuals and ecosystems investigated. Research on relevant pathogens and trace organics is particularly rare.

SOIL AND PUBLIC HEALTH

Soil, a thin veneer of material often less than one meter thick, forms a fragile, living "skin" on Earth's terrestrial surface. Human life as we know it depends absolutely on soil, which has recently been described as "the most complicated biomaterial on the planet" (Young & Crawford, 2004). The complexity of soil results from two components: the *abiotic soil architecture* and *biotic diversity*.

The abiotic architecture depends on mixes of different sized sand, silt and clay particles, which collectively determine important variables such as surface area within the soil matrix and a variety of chemical reactions and transformations. The amount of surface within a soil and its reactivity also control chemical sorption (including pollutants), nutrients and even microbes. Soil composition also partially regulates water movement and retention as well as aeration. These soil properties can all be altered beneficially or adversely by land application of organic residuals.

The diverse soil microflora control degradation reactions in soil. In order of increasing size, the major soil biota consist of viruses, bacteria, fungi, algae and protozoa. A gram of soil literally contains many billions of organisms. This means that 10^{18} soil microorganisms (*i.e.,* a million million million) are in the soil around a typical quarter acre residence.

These microbes are overwhelmingly beneficial, carrying out processes that promote plant growth, protect human health and maintain ground water quality. However, a small minority can cause human, animal and plant diseases, for example, bacteria such as *Bacillus anthracis*, fungi such as *Cocciodes immitis*, and protozoa such as *Naegleria fowleri,* while others are sources of antibiotic resistance. Nonetheless, soils per se are rarely a cause of disease, perhaps because vastly greater numbers of beneficial microbes limit the growth and activity of the relatively few naturally occurring pathogens. Beneficial microbial populations in soils, as well as soil conditions more generally, also inactivate fecal pathogens that might be introduced into soil via land application of organic residuals.

V. RESEARCH NEEDS

While there has been a substantial amount of research conducted on organic residues, there remain a number of important questions and issues that need to be addressed through additional, focused research programs.

- How much do organic residuals like manures and biosolids contribute to terrestrial carbon sequestration through long term land application? How does the contribution vary with changing climate or different management regimens?
- How does land application of organic residuals affect greenhouse gas emissions, especially nitrous oxide (N_2O)?
- What is the overall impact on atmospheric CO_2 (*i.e.,* the carbon footprint) of land application of organic residuals, as evaluated via "triple bottom line" and life cycle analysis?
- What are the mechanisms of transport, the ultimate fates, and the impacts of chemical and microbial contaminants associated with land application of organic residuals?
- Under what conditions is land application of organic residuals sustainable, and how does sustainability vary with soil type, management, land use and climate?
- Based on quantitative microbial risk assessments, what are the health risks from exposure to microbes that result from land application of organic residuals?
- How does land application of organic residuals impact critical ecosystems, including those microbial communities that are integral to plant and soil health?

Front-end loader collecting chicken litter in Mississippi

VI. RECOMMENDATIONS

Over the last five decades, hundreds of field and laboratory studies have contributed to an enormous knowledge base on the benefits and potential hazards of land application of organic residuals. Nonetheless, important gaps in knowledge remain, as does the need to better communicate existing knowledge to the public and to policymakers.

We therefore recommend the following:

- **Promote effective communication among regulatory agencies such as EPA, policymakers, researchers and the general public.** Such communication should include clear explanations of potential risks for land application of biosolids and animal manures in particular, as well as the potential benefits.

- **Establish Long term Observatories (LTOs) for organic residuals at land application sites.** Such observatories should monitor on decadal time scales the fates, as well as the health and ecological impacts, of multiple organic residuals applied with multiple methods, in different U.S. climatic regions using well instrumented, interdisciplinary research teams.

- **Develop and validate new methods for identifying and quantifying existing and emerging contaminants.** For microbial contaminants, method development should focus on rapid, high throughput molecular and genomic approaches that support quantitative microbial risk assessments.

- **Develop and enforce best management practices for land application of manures.** Best management practices should be science based and incorporate quantitative risk assessments to optimize environmental benefits and minimize potential hazards. Risk assessment models and existing guidance (*e.g.,* rules and BMPs) should be field validated.

Application of swine manure lagoon effluent to Mississippi hay field

B

GLOSSARY

Biosolids result from physical separation and subsequent regulated treatment or digestion of the solid matter in sewage. Treatment produces either Class A or Class B designations (National Research Council, 2002).

Class A biosolids, which are produced by anaerobic and aerobic digestion and/or composting, contain no detectable pathogens. Biosolids meeting Class A standards can be used beneficially, for example, in home or agricultural applications guided by local and state regulations.

Class B biosolids contain one or more detectable pathogens, and beneficial uses are substantially constrained. They can be applied to agricultural land under restricted conditions, buried in landfills, incinerated, or treated further to reach Class A standards.

Endocrine disrupting compounds comprise a diverse group of pharmaceuticals, plant products, pesticides and chemicals used in plastics and numerous consumer and industrial products. Endocrine disrupting compounds can cause a wide range of health effects in humans and wildlife by interfering with hormone receptors in the endocrine system. Endocrine disrupting compounds can be introduced to biosolids through sewage treatment systems; personal care products and other consumer chemicals represent significant sources of endocrine disrupting compounds.

Endotoxins are produced by bacteria; they are typically structures associated with cell membranes, and elicit immunological responses and contribute to pathogenicity.

Liquid biosolids application via injection in Tucson, Arizona

Eutrophication results from the introduction of excess nutrients (typically nitrogen or phosphorus) into aquatic ecosystems (lakes, rivers, coastal waters) leading to "blooms" of algae or other plants, usually with adverse effects

Organic residuals refers broadly to organic wastes, including sewage and manures and food and plant wastes produced individually, commercially and by various governmental organizations.

Prions, or proteinaceous infectious particles, are proteins that cause several neurodegenerative diseases, including bovine spongiform encephalopathy (BSE or "mad cow disease") and Creutzfeldt-Jakob disease (CJD).

Triple bottom line (TBL) accounting considers social and environmental costs and benefits in addition to economic costs and benefits for a given process or activity; the goal of TBL accounting provides a framework for more fully assessing sustainability than analyses based on economic considerations alone.

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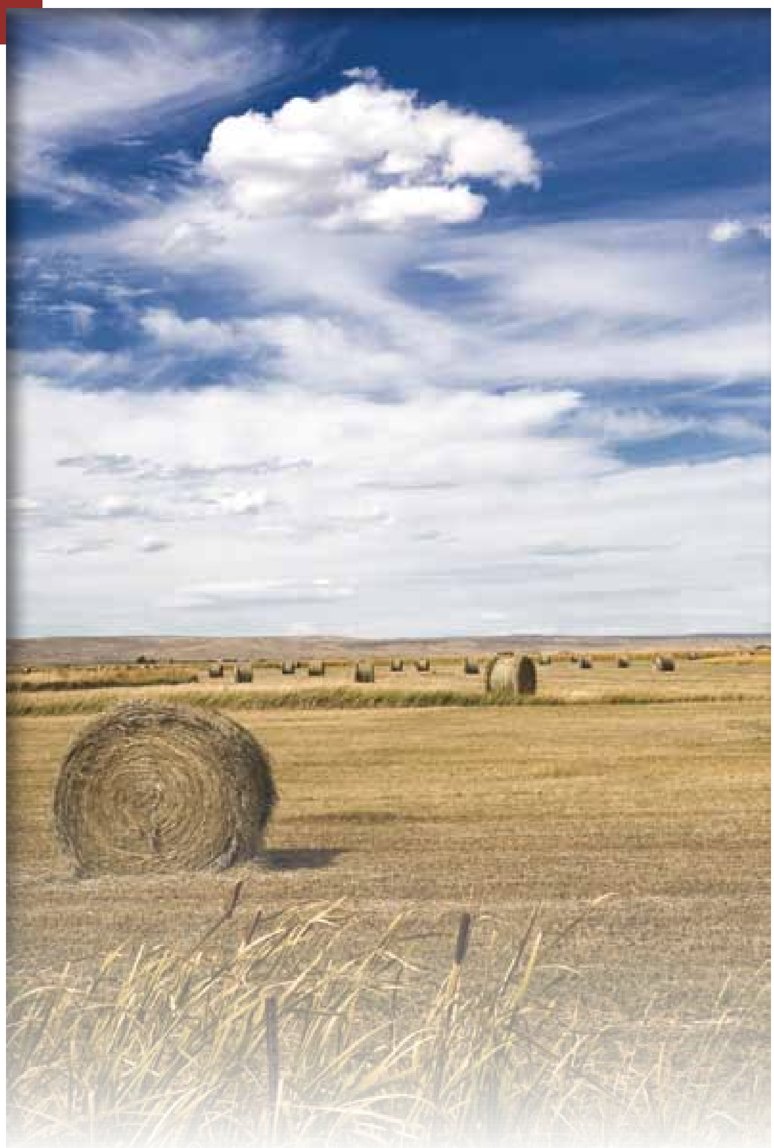

PUBLIC PERCEPTION AND WASTE MANAGEMENT TWO CITIES, TWO STORIES

The Mayor of San Francisco has recognized the value of organics for soil applications and promotes their use to achieve environmental benefits and the greater goal of sustainability. However, that vision for recycling appears increasingly to exclude biosolids. The city's current give away program for composted biosolids has recently been highly criticized by the Organic Consumers Association and the Center for Food Safety, two public interest and environmental advocacy groups. The groups claim that biosolids compost, which they consider a 'highly toxic sludge", belongs in a hazardous waste dump. They also note the presence of a wide range of chemical compounds in the biosolids as additional proof of toxicity. These compounds derive from common household products that include seat cushions and plastic food containers. Such protests against biosolids use have received widespread national coverage. Largely as a result of these concerns, San Francisco now is studying methods to dispose of biosolids through combustion. In this case, societal concerns, poor communication, and a misinformed population may be sufficient to force a municipality to abandon a cost effective and environmentally sustainable practice in favor of a more expensive disposal option that produces no agricultural benefits.

In contrast, the city-of Tacoma, Washington, has one of the nation's best and well received biosolids recycling programs. This has been achieved through a long term public outreach program that goes hand in hand with a product development effort. The city initially produced pathogen free biosolids that had a high moisture content and somewhat objectionable odor. The first attempts to market this material in the early 1990s failed. Tacoma then partnered with researchers at Washington State University and local master gardeners to create a product that had a non objectionable appearance and clear benefits when used in urban gardens. Products were marketed at the state fair and at flower and garden shows. Information was also distributed in utility bills. The city now markets TAGRO Mix and TAGRO Potting Soil. The website advertises TAGRO (short for Tacoma Grown) as an award winning, environmentally friendly product that will "give you better results with your lawn and garden, even while you help to reuse community resources and protect our environment." Although program staff receives occasional calls expressing concerns about the safety of the product, the customer base for TAGRO is so large that such calls are no longer a serious concern.

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