Managing Manure to Minimize Environmental Impact

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J H Harrison[1], J M Gay[2], R McClanahan[2], E Whitefield[1], O Saunders[3], and A M Fortuna[3].

[1]Department of Animal Science, WSU-Puyallup Research and Extension Center, 2606 West Pioneer, Puyallup, WA, 98371
Email: jhharrison@wsu.edu
Email: e.whitefield@wsu.edu

[2]WSU CVM AAHP Field Disease Investigation Unit, WSU-Pullman,
POB 646610 Pullman, WA 99164-6610
Email: jmgay@vetmed.wsu.edu
Email: rmcclanahan@vetmed.wsu.edu

[3] Department of Crop & Soil Sciences Phone: (509) 335-1859
Washington State University FAX: (509) 335-8675
291D Johnson Hall, P.O. Box 646420
Email: afortuna@wsu.edu
Email: osaunders@wsu.edu

Take Home Messages

- Manure is a valuable source of nutrients for crop production, but can also be a source of pathogens which could raise bio-security and human health concerns
- Best management practices exist to minimize the impact of manure management on the environment
- Anaerobic digestion of manure reduces common pathogens in manure by at least 90%
- When land applied, anaerobically digested manure has significantly fewer bacteria, both initially and for weeks thereafter
- As more manure is moved off-farm for human crop production, greater attention needs to be given to insuring that the manure presents a low risk of contaminating food crops

Introduction

This paper will focus on aspects of manure management related to the fate and transport of microorganisms and pharmaceuticals to the environment. Other presentations at this conference will address nutrients related to environmental impact. The intent of this summary is to bring awareness of the potential impact of manure on the environment, and practices which can minimize that risk.

Manure is a biologically active material which hosts and supports many microorganisms, and thus can seldom be considered “pathogen free”. Certain manure handling techniques and methods however can limit the production and multiplication of such pathogens. In addition, common antibiotics and hormones have also been documented in animal manures. Awareness and risk assessments must be considered in developing best management practices and policy related to manure handling.

Microorganisms and Pharmaceuticals

There are over 150 pathogens, or disease-causing microorganisms, in livestock manure which pose a risk to humans (Strauch and Ballarini, 1994; USEPA, 2003). Common food borne illnesses include the viruses hepatitis E, Reoviruses, Rotaviruses, and Influenza, the bacterium *Campylobacter* spp., *Escherichia coli* O157:H7 and generic E. *coli* spp., *Salmonella* spp., *Vibrio* spp., *Leptospira* spp., *Listeria* spp., and the parasites *Giardia lamblia*., Cryptosporidium *parvum*., and *Balantidium coil*. Many of these pathogens are prevalent in manure and are difficult to remove from a facility (USEPA, 2003; Sobsey et al., 2001). Some, such as E. coli O157:H7 and certain *Campylobacter* spp., are not pathogenic for the host species from which the manure originated but are for other species exposed to the manure containing the agent.

Land application of dairy manure poses a risk to both humans and grazing animals as pathogens applied in manure are known to survive in soil long after application (Avery et al., 2004; Nicholson et al., 2005). The United States has observed a growing number of food borne illnesses associated with crop contamination (Doyle and Erickson, 2008). Many cases of food borne illness have been linked to livestock production and animal manures (Smith and Perdek, 2003; CDC, 2006). Manures or irrigation water applied to vegetable crops which are subsequently consumed raw, or to grain crops, can contaminate food for human or animal consumption (Mead and Griffin, 1998).

The fate of antibiotics used at concentrated animal feeding operations (CAFOs) has gained recent attention by the regulatory community. Watanabe et al. (2010) reported the occurrence of antibiotics in the environment on two dairies. Samples were collected at the points of use of antibiotics and subsequent points of manure handling. They observed that although antibiotics had been used for decades on these two dairy farms, the antibiotics seemed to be detected within farm boundaries. Antibiotics were most frequently detected at lagoons, hospital pens, and calf hutches. Some evidence of sulfonamides were found in shallow ground water, while tetracyclines were identified in soils. Evaluation of field surface samples demonstrated the presence of antibiotics on fields where manure had been applied, but not in the sandy subsoil.

Resistance of bacteria to antibiotics continues to be a concern of medical health professionals and veterinarians alike. Reducing the effectiveness of proven antibiotics would be costly for meat, milk, and egg production; and, potentially increasing the risk for bacterial infections insensitive to common antibiotics in humans. West et al., (2010) documented the presence of antibiotic resistant bacteria in samples from waterways in close proximity to waste-water treatment plants and CAFOs. From 830 environmental bacterial isolates, 77.1% were resistant to only ampicillin, while 21.2% were resistant to combinations of antibiotics including ampicillin (A), kanamycin (K), chlorotetracycline (C), oxytetracycline (O), and streptomycin (S). Multi-drug-resistant bacteria were significantly more common at sites close to CAFO farms.

Numerous studies have documented the presence of hormones in manure and their subsequent fate when manure is stored in manure lagoons or applied to crop land (Dutta et a., 2010; Khanal et al., 2006: Lorenzen et al., 2004; Raman, et al., 2004; Hansleman et al., 2003; Arnon et al., 2008; and Zhao, Knowlton, and Love., 2008). The general concern is the endocrine disrupting properties that result for wildlife and aquatic life when these hormones or conjugates are transported to ground and surface water. Treatment of manure via anaerobic digestion or composting can decrease the amount of estrogens detected in manure (Zhao, Knowlton, and Love, 2008). While there is still much to be learned, it is apparent that hormones or their conjugates to have an ability to persist in the environment. An excellent webcast for additional information related to the occurrence of antibiotics and hormones in water, and their fate, transport and best management practices (http://www.extension.org/pages/Antibiotics_and_Hormones:_Occurrence_in_Water,_Fate_and_Transport,_and_Best_Management_Practices).

Factors affecting Microorganism Fate and Transport

Microorganisms in land applied manure are affected both positively and negatively by factors affecting their ability to survive. Figure 1 depicts the factors affecting the viability of pathogens along transport pathways. In general, cool temperatures, moist conditions, and lack of direct-sunlight promotes the survival of microorganisms; while UV light, drying conditions, and limited crop canopy promote die-off of microorganisms (Sobsey et al., 2001).

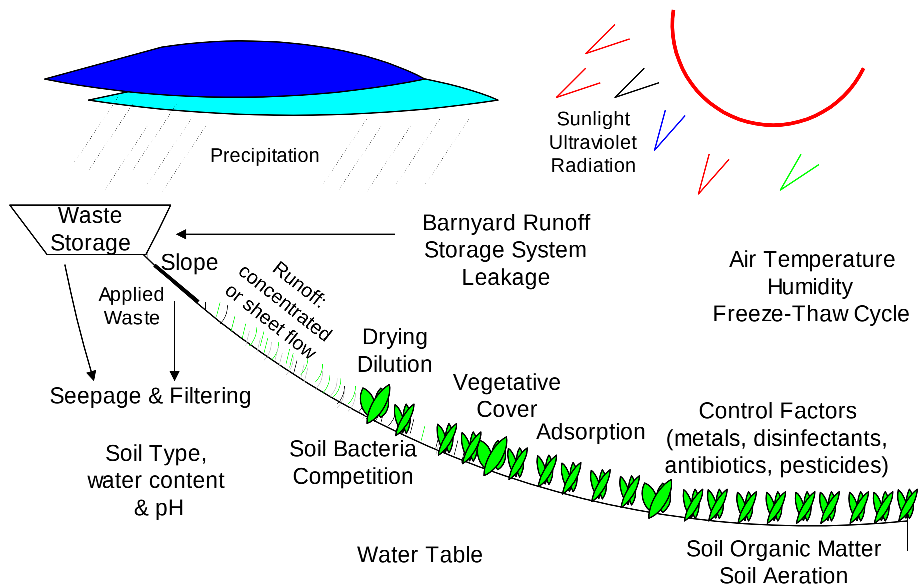


Figure 1. Factors affecting the viability of pathogens along transport pathways
Source: Fate and Transport of Waterborne Pathogens. Water Quality Teleconference July 10, 2001. Barry Rosen. NRCS-Watershed Science Institute

Aerial application of manure can result in the development of bio-aerosols which promote the transport the bacteria via wind. Movement downwind of as far as 4 miles has been documented for salmonella (Sobsey et al., 2001). In addition to bacteria, endotoxins can also be transported via wind and particulate matter (Sobsey et al., 2001).

Tillage practices or lack of tillage can promote the movement of bacteria via macropores or channels developed by earthworms. For many decades we have promoted no-till or minimum till practices to decrease soil sediment loss to surface water and improve soil tilth. An unintended consequence of this practice is the extensive network of channels that are developed by earthworms beneath the soil surface.

These channels have been shown to provide direct connections with tile drains and promote the transport of bacteria and pesticides to tile drain lines (Fox, Kanwar, and Malone, 2008).

Managing Manure to Minimize Environmental Impact

Numerous best management practices have been developed which can minimize the environmental impact of manure. Figure 2 lists the common practices as described by the USDA Natural Resources Conservation Service. The practices fall into one of three general categories of: 1) collection and storage of manure, 2) minimizing off-field movement of manure, and 3) limiting direst access of animals to surface water.

Management Practices for Pathogens

Goals:
Prevent/Reduce Organism Movement to Water &
Facilitated Organism Die-off

Mode of Action: Organism/Sediment Trapping-Biological

Channel Vegetation (AC) (322)
Conservation Cover (AC) (327)
Critical Area Planting (AC) (342)
Field Border (FT) (386)
Filter Strip (AC) (393)
Grassed Waterway (AC) (412)
Heavy Use Area Protection (AC) (561)
Pasture and Hay Planting (AC) (512)
Prescribed Grazing (AC) (528A)
Riparian Forest Buffer (AC) (391)
Riparian Herbaceous Cover (AC) (390)
Streambank and Shoreline Protection (FT) (580)
Vegetative Barriers (FT) (601)
Wetland Creation (AC) (658)

Mode of Action: Structure/Management

Roof Runoff Management (NO.) (558)
Waste Storage Facility (NO.) (313)
Waste Utilization (AC) (633)
Closure of Waste Impoundments (NO) (360)
Composting Facility (NO.) (317)
Manure Transfer (NO) (634)
Waste Treatment Lagoon (NO.) (359)

Mode of Action: Organism/Sediment Trapping-Physical

Anionic Polyacrylamide (PAM) Erosion Control (AC) (450)
Constructed Wetland (AC) (656)
Contour Buffer Strips (332)
Contour Farming (AC) (330)
Contour Stripcropping (AC) (585)
Controlled Drainage (AC) (335)
Deep Tillage (AC) (324)
Grazing Land Mechanical Treatment (AC) (548)
Sediment Basin (NO.) (350)
Stripcropping (AC), Field (586)
Subsurface Drain (FT) (606)
Surface Drainage (FT), Field Ditch (607)
Surface Drainage (FT), Main or Lateral (608)
Terrace (FT) (600)
Water and Sediment Control Basin (NO.) (638)

Mode of Action: Reduced Direct Access and Subsequent Deposition

Animal Trails and Walkways (AC) (575)
Fence (FT) (382)
Use Exclusion (AC) (472)
Watering Facility (NO.) (614)

Anaerobic Digester Technology and Environmental Quality

Anaerobic digesters (ADs) have been adopted for purposes of odor control, electricity generation, greenhouse gas emission reduction (methane), and nutrient management. An added benefit not often mentioned is the reduction of potentially pathogenic microorganisms. The most common type of AD is the mesophyllic, which operates at ~ 100 degrees F. It has been commonly reported that mesophyllic AD can reduce pathogenic bacteria by 90 – 95% (Harrison and Saunders, 2010).

Since 2008 the Livestock Nutrient Management Unit at Washington State University has been evaluating the fate and transport of microorganisms when dairy manure and pre-consumer foodwastes are treated with anaerobic digestion. To evaluate bacterial survival in manure that was AD, undigested and post-AD duplicate manure samples were obtained twice per month for comparison of Salmonella, Generic *E. coli* (GEC), E.coli 0157:H7, Enterococci (EC), Listeria, *Mycobacterium paratuberculosis* (Johnes), and Campylobacter survival. In addition, a limited number of samples of pre-consumer food-waste (commodity) was also tested. Generic *E. coli* was selected because high concentrations are dependably present in bovine fecal waste, and, because of its relatively low thermotolerance as a representative gram (-) organism, survival of this organism in residues would indicate that a wide variety of biosecurity agents could likely survive. Enterococci were selected because they are dependably present in bovine fecal waste, and, because of their relatively high thermotolerance as a representative gram (+) organism, survival of these organisms in residues would indicate that thermotolerant biosecurity agents could likely survive. Salmonella and *Mycobacterium paratuberculosis* were selected because they are themselves important biosecurity agents, because they occur frequently enough in dairy herds that a good chance exists of finding them (at least in pre-digestion samples), and because they are environmentally resistant to a lesser (Salmonella) or greater (*Mycobacterium*) degree. Quantitative counts were made on GEC and EC, while presence–absence after selective enrichment was noted for salmonella, mycobacterium paratuberculosis, Listeria, and Campylobacter. Figure 3 and 4 summarize the Box and Whisker plots of GEC and enterococci bacteria at different points in the manure handling system. Table 1 and 2, and figures 3 and 4 summarize information related to the fate of bacteria when evaluated in fresh feces, fresh manure, bedding, feedstocks, the manure and feedstock mixture (receiver), post AD effluent, post AD solids, post AD liquids, and aerobic composted solids. The results demonstrate that the AD treatment resulted in a 2 log reduction in enterococci (LogEnt, receiver tank – median 3.93, and AD Effluent- median 2.78) and a 2.5 log reduction generic *E-coli* (LogGEC, receiver tank - median 4.51, and AD Effluent - median 2.02). Composting the manure solids after AD resulted in a further reduction to median Enterococcus count of 0 and median generic *E. coli* count of 0.

Table 1. Description of sampling points and number of samples for bacterial counts or presence-absence of bacteria (see figures 3 and 4, and table 2 for data).

Sampling Location	Description	Log Enterococci # samples	Log GEC # samples
Feces	Feces sampled at the farm	25	25
Farm Flow	Manure as received at the digester via 1 mile pipeline from the farm	26	27
Bedding	Mixed shavings and manure from dry-cow and heifer barn at digester site	22	23
Commodity	Addition feedstocks received at digester: includes whey, fish-stick processing waste, blood from slaughter plant, and egg waste,	6	6
Receiving Tank	Manure and feedstock mix	27	26
Effluent after anaerobic digestion	Effluent emerging from anaerobic digester	30	30
AD Solids	Solids after anaerobic digestion and liquid-solids separation	26	24
SepLiquid	Liquid after anaerobic digestion and liquid-solids separation	44	44
Compost	Composted AD solids	21	21
Calf Barn	Surface liquid run-off from calf barn at digester site (does not enter digester, but goes to the AD effluent storage lagoon)	10	9

Figure 3. Box-Whisker plot of generic e-coli bacteria in pre- and post AD materials. Wilcoxon Rank Sum Test indicated that the reduction in Log GEC due to anaerobic digestion, Receiver site compared to Effluent site, was a statistically significant.

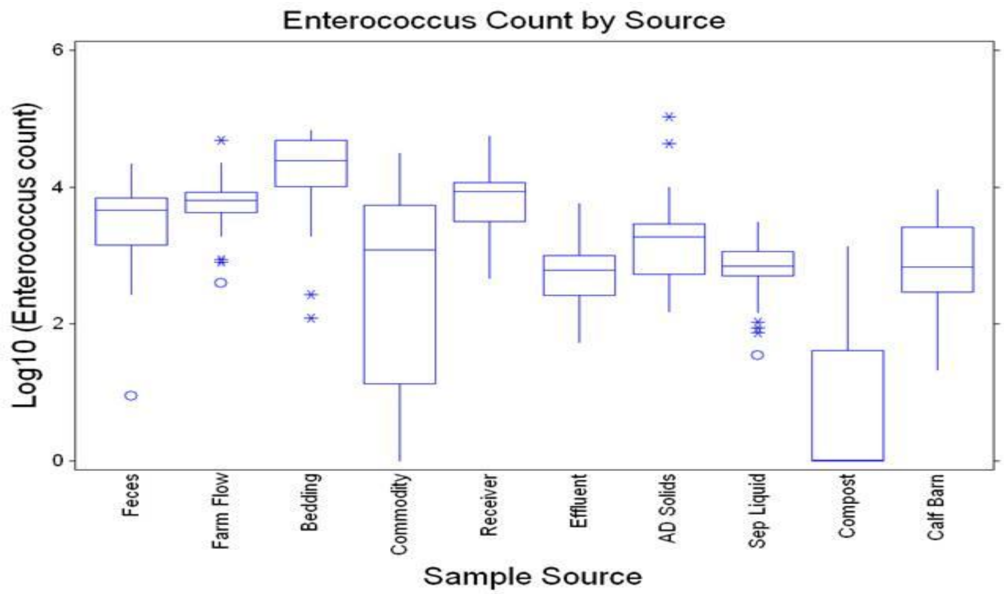
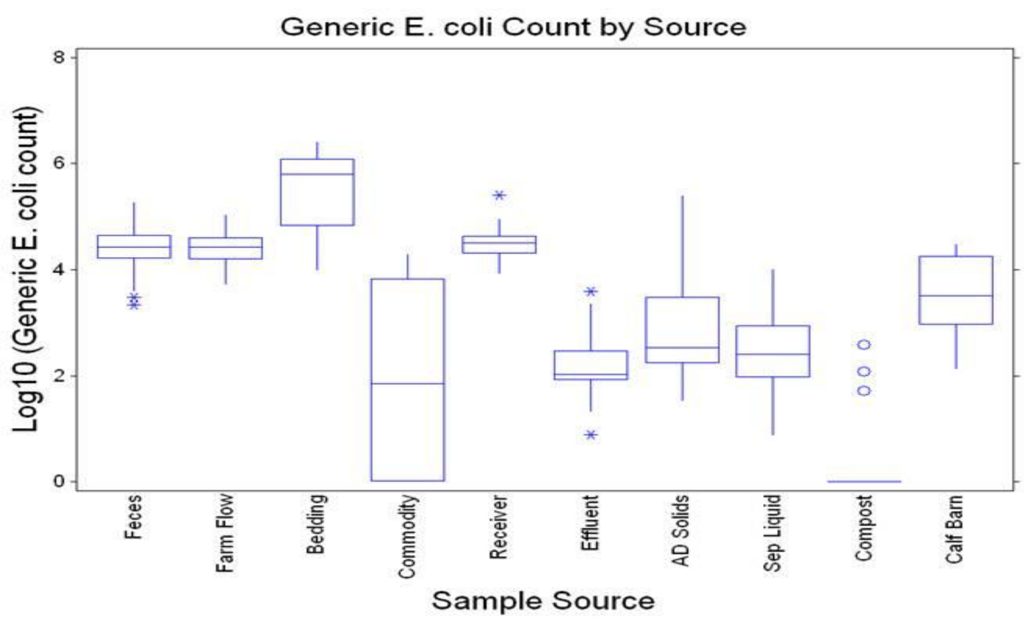


Figure 4. Box-Whisker plot of enterococci bacteria in pre- and post AD materials. Wilcoxon Rank Sum Test indicated that there was the reduction in Log enterococci due to anaerobic digestion, Receiver site compared to Effluent site, was statistically significant.



The presence-absence data for Campylobacter, Listeria, *Mycobacterium paratuberculosis*, and Salmonella are summarized in Table 2. Common patterns were: 1) Campylobacter – a reduction in presence after AD, and no detection in composted solids; 2) Listeria – little or no reduction due to AD, and no detection in composted solids; 3) *Mycobacterium paratuberculosis* – small reduction in presence after AD, and no detection in composted solids; and, 4) Salmonella – increased detection after AD, and no detection in composted solids. With the exception of one commodity sample (eggwaste) with a detection of salmonella, the selected bacteria were not detected in these sources. .

Table 2. Presence-absence of bacteria in pre- and post-AD materials.

Sampling Location	Campylobacter	Listeria	*Mycobacterium paratuberculosis*	Salmonella
On-farm Feces	56% (14/25)	12% (3/25)	84% (21/25)	44% (11/25)
Farm Flow	35% (9/26)	4% (1/26)	78% (21/27)	77% (20/26)
Bedding	0% (0/22)	0% (0/22)	9.5% (2/21)	27% (6/22)
Feedstocks	0% (0/4)	0% (0/4)	33% (0/6)	17% (1/6)*
Receiving Tank	28% (7/25)	0% (0/25)	63% (17/27)	89% (24/27)
Effluent after anaerobic digestion	28% (8/29)	7% (2/29)	71% (22/31)	90% (28/31)
AD Solids	0% (0/23)	9 % (2/23)	32% (8/25)	84% (21/25)
SepLiquid	7 % (3/43)	5 % (2/43)	54 % (24/44)	79% (35/44)
Compost	0% (0/20)	0% (0/20)	0% (0/19)	0% (0/20)
Calf Barn	50% (4/8)	0% (0/8)	33% (2/6)	50% (4/8)

* source was egg waste

In 2009 – 2010 the survival or die-off of fecal coliform and *Escherichia coli* on soil after manure application was characterized in field based experiments (Saunders, 2011). Fresh and AD manure was applied to replicated plots of grass to be harvested for silage. Manure was applied via two methods, subsurface application and surface broadcast application. Subsurface deposition was accomplished with a 3.05 meter Aerway® Sub Surface Deposition (SSD) (Model AW1000-2B48-D) with a custom Banderator® attachment for application of manure through eight PVC pipes attached to the Banderator® tines. Tines were set to drop ~ 10 cm below the soil surface creating intermittent slices 12.5 cm in length at the surface. Surface broadcast of non AD manure [before digestion, or (BD)] and AD manure was applied using drop hoses connected with the Aerway® ™ system in the up position.

Soil cores of 1 inch deep by 2 inch diameter were sampled from each plot with after manure application to determine the die-off of fecal coliform and *Escherichia coli*. These organisms are used as indicator pathogens because they are commonly present in the fecal material of warm blooded animals, and are affected by anaerobic digestion. The rate of indicator bacteria decline is presented in Table 3 for each trial. The slope of the line over time began at the peak day of bacterial concentration and continued until the final day of sampling, prior to the next manure application.

Table 3. Individual die-off rate of bacteria over each sampling period (rate = log CFU/100 gm soil/day).

			Treatment			
			AD-SSD	AD-B	BD-SSD	BD-B
			Rate of bacterial decline (day^{-1})			
2009	May	Fecal coliform	-0.0489	-0.0185	-0.0162	0.0096
		E. coli	-0.0345	-0.0143	-0.0357	0.0443
	Jun	Fecal coliform	-0.0834	-0.0794	-0.1129	-0.0621
		E. coli	-0.0645	-0.0722	-0.0939	-0.0580
	Aug	Fecal coliform	-0.2454	-0.3119	-0.2457	-0.7166
		E. coli	-0.3284	-0.1994	-0.2313	-0.3257
2010	June	Fecal coliform	-0.2496	-0.0995	-0.1451	-0.1102
		E. coli	-0.1700	-0.0900	-0.1268	-0.0924
	July	Fecal coliform	-0.2235	-0.1446	0.0712	-0.4307
		E. coli	-0.1691	-0.1154	0.0523	-0.3373

AD-SSD, Anaerobically digested – subsurface deposition; AD-B, Anaerobically digested – broadcast applied; BD-SSD, Before digestion – subsurface deposition; BD-B, Before digestion – broadcast applied.

Statistical significances are presented in Table 4 as an average of all trials over two seasons. Soil receiving the before digestion-broadcast applied (BD-B) manure saw the greatest reduction rate in fecal coliform (-0.254), followed by AD-SSD manure (-0.170). Terminal day sampling indicated AD-SSD had the fewest fecal coliforms (2.096 $\log_{10}$ CFU 100g soil^{-1}), while BD-B had significantly more (3.445 $\log_{10}$ CFU 100g soil^{-1}). The greatest rate of decline of bacteria numbers occurred when ambient temperatures were highest. This study found that over five different application trials, with varying environmental conditions, anaerobically digested manure had significantly fewer indicator bacteria, both initially and at the end of the sampling period in a field of forage grasses.

Table 4. Average rate of bacterial die-off from all sampling periods during 2009 and 2010 seasons. (rate = log CFU/100 gm soil/day)

	Fecal coliform		*E. coli*	
	Rate of bacterial decline (day^{-1})			
AD-SSD	-0.170	ab	-0.153	a
AD-B	-0.131	b	-0.098	ab
BD-SSD	-0.090	b	-0.087	b
BD-B	-0.254	a	-0.145	ab

AD-SSD, Anaerobically digested – subsurface deposition; AD-B, Anaerobically digested – broadcast applied; BD-SSD, Before digestion – subsurface deposition; BD-B, Before digestion – broadcast applied. Letters indicate significant statistical differences at $\rho=0.05$.

Education Resources

The following webcasts and websites are recommended for further understanding of the factors related to pathogens and pharmaceuticals in manure.

- http://www.extension.org/pages/Potential_Routes_for_Pathogen_Transport_to_Water
- Animal Science Societies (FASS) hosted a webinar titled "Antibiotics in Animals and People" on October 20, 2010. http://www.fass.org/policy_webinar.asp
- http://www.waterbornepathogens.org/
- http://www.extension.org/pages/Manure_Pathogen_Articles
- Webinar – Antibiotics and Hormones: Occurrence in Water, Fate and Transport, and Best Management Practices. http://www.extension.org/pages/Antibiotics_and_Hormones:_Occurrence_in_Water,_Fate_and_Transport,_and_Best_Management_Practices
- Veterinary Medicines in the Environment - http://toxics.usgs.gov/highlights/vet_meds.html

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