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REVIEW ARTICLE

Application and Environmental Risks of Livestock Manure

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Abstract Over the past few decades, livestock production has undergone an industrial revolution, resulting in the large-scale generation of livestock manure. Livestock manure has many beneficial nutrients, which can improve agricultural crop production, and is an organic alternative to chemical fertilizers. Livestock manure requires proper treatment before application to agricultural land, because it contains toxic heavy metals and pathogenic microorganisms. When improperly treated, stored or used, livestock manure can pollute rivers, soil ecosystems, and underground drinking water, thereby affecting all living organisms nearby. In this article, we illustrate the land applications and environmental risks associated with the use of livestock manure.

Keywords environmental risks · heavy metals · pathogenic microorganisms · livestock manure · organic fertilizer

Livestock manure is an important resource of organic matters, useful microorganisms, and plant nutrients. Manure contains both organic and inorganic nutrients that may be dissolved into or suspended within the liquid phase. The inorganic nutrients present in livestock manure include the primary nutrients (N, P, K, and S), the secondary nutrients (Ca and Mg), and micro nutrients (B, Cl, Cu, Fe, Mn, Mo, and Zn). On the other hand animal feeds contain toxic heavy metals and was detected in plants grown on manure-applied agriculture fields (Zhou et al., 2005). The presence of heavy metals in the agriculture land not only affects the plants, but also cattle grazing in the fertilized pastures land (by ingestion of soil and pasture). The presence of heavy metals in body tissues of cattle fed in slurry-amended pasture lands in Galicia, North-Western Spain has been reported (López-Alonso et al., 2000; 2002). Livestock manure also contains large numbers of pathogenic microorganisms, which can potentially pose risks to human health. The easiest mode of transmission of pathogens from animals to humans is through direct contact. Concentrations of some pathogens exist at levels of millions to billions per gram of wet weight feces or millions per milliliter of urine (Sobsey et al., 2006). Quessy et al. (2005) reported that microorganisms such as *Salmonella*, *Yersinia enterocolitica*, *Listeria monocytogenesis*, and *Crytosporidium* in cattle, poultry, and swine manure are able to survive in typical storage conditions used on livestock farms, and most of these organisms can be detected in the soil following land application of the manure. In this review, we discussed the land applications and environmental risks associated with the use of livestock manure.

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Livestock Manure Production and Land Application in Korea

The livestock industry is traditionally one of the most important agricultural practices in Korea, though it generates enormous amounts of waste. According to Jeong et al. (2011), approximately 86.6% of the total livestock manure produced is recycled to farmlands as compost and liquid fertilizer. Livestock manure in Korea is treated in three possible ways. The first and the most common method is to mix manure with straw or sawdust and store it in a composting area for several months. Another method is to transform the manure into liquid fertilizer through fermentation. These two methods process livestock manure for agricultural use. The third method is to purify the manure to meet certain criteria (less than BOD 150 mg L^{-1}, for example) and then discharge it into rivers. Currently, 83% of Korean farms have composting facilities, 5% have liquid fertilizer processing facilities, and only 7.5% have manure purification facilities. Composting is a viable method of treating livestock manure and maximizing its beneficial effects through reuse on agricultural lands. It is also encouraged as a sustainable agriculture practice for farmers. The principal requirement for the use of compost in soil is the degree of stability or maturity, which implies stable organic matter contents, and the absence of phytotoxic compounds as well as plant and/or animal pathogens. Thus, it is important to evaluate the maturity and quality of the final product to protect crops and the environment. The Korean commercial compost guidelines, established in 1977, have been modified 13 times. These guidelines include criteria for components such as hazardous ingredients, organic matter, nitrogen, and water content, as well as a list of organic sources that must not be used for composting.

Generally, manure generated by livestock is returned to the soil to improve its tilth and fertility. Both the United States Department of Agriculture and United States Environmental Protection Agency recognize that land application is the best method of utilizing animal manures. However, if the manure is not applied properly or if the manure load exceeds the site's nutrient demands, ground and surface water quality can become impaired. Gasser et al. (2005) studied the nitrogen balance in potato fields fertilized with liquid swine manure, taking into account crop uptake and nitrate leaching. They found that approximately 60% of the manure nitrogen was not utilized, suggesting important nitrogen losses through ammonia volatilization, denitrification or immobilization in soils. The phosphorous present in livestock manure may be lost to surface or groundwater through run-off or leaching. Once in the soil, phosphorous is immobile, because it is tightly held by soil particles, and surface applied phosphorus may also be lost through erosion of the surface soil.

Livestock manure can be applied to the land for recycling by soil-crop systems using four broad techniques such as broadest surface application, banded surface application, direct injection, and incorporation

Environmental Risks of Livestock Manure

Effects on water and the arable soil system. Livestock manure that enters streams, ponds, lakes or ground water is a major concern due to four factors: nutrients, oxygen depletion, suspended solids, and bacteriological quality. Nutrients such as nitrogen, phosphorous, and potassium not used by the animals are returned to the soil, where they are used by the crop (Fig. 1). However, when proper management is not used in spreading the manure, erosion, runoff, and leaching may transfer the nutrients away from

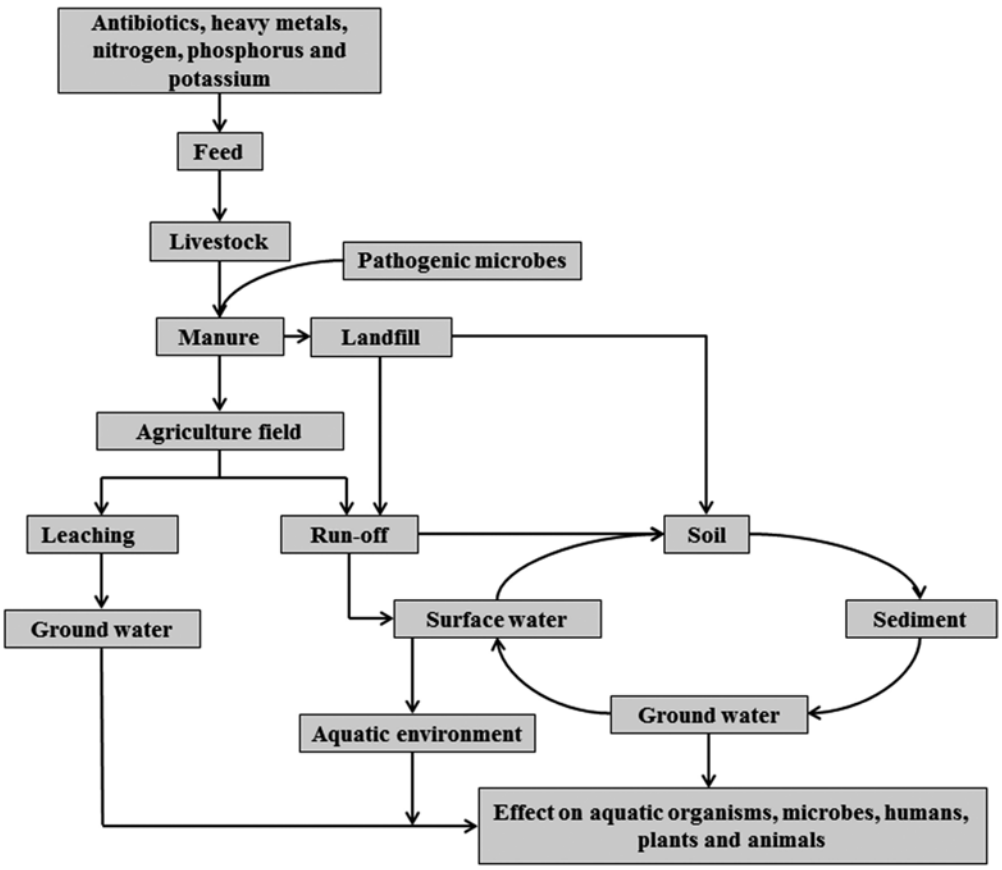

Fig. 1 Fate of pollutants into the environment through livestock manure (Modified from Kumar et al., 2012)

the soil and into water sources, causing pollution. The organic material in the manure will decompose and consume the dissolved oxygen in the water, possibly resulting in the death of fish. Settled solids and nitrogen compounds can kill aquatic life forms. Nutrients in the manure may increase the growth of aquatic plants, which can disrupt the local ecosystem. Bacteria and viruses may be introduced, increasing the potential for spreading disease, and excessive nitrates in drinking water can create a health hazard for humans (especially young children) and reduce the performance of livestock. Excessive application of manure to soils can result in the buildup of nutrients in the soil. When nutrient concentrations become too high, nutrients such as nitrate-nitrogen can move through the soil into groundwater. A prolonged over-application of manure can lead to an imbalance in the soil chemistry that will result in reduced crop yields. High concentrations of manure are toxic to plants. Within one year of manure application, grasses, root crops or some type of flora must be planted to take up the nutrients applied to the soil. Soil compaction should be minimized by not driving repeatedly over the area with heavy tanks of manure. The application of animal livestock manure to agricultural land may result in serious environmental problems, such as nitrate and phosphate contamination of surface waters (Smith et al., 2007).

Risks due to heavy metals and pathogenic microorganisms in livestock manure. Livestock manure is an alternative source of fertilizer in organic farming (Wong et al., 1999), and an economical substitute for chemical fertilizer. However, some environmental risks may result from the application of manure, including the salt toxicity of manure to plants (Meek, 1974), and the accumulation of trace metals in plants that may pose a health risk when humans or livestock consume them. Heavy metal residues in manures can accumulate in surface soils as a result of long-term agricultural use (Adeli et al., 2007; He et al., 2009; Shi et al., 2011). The accumulation of heavy metals could not only affect soil fertility and product quality (Guan et al., 2011), but may also promote metal migration through leaching and runoff (Azeez et al., 2009). Zhou et al (2005) investigated zinc and copper concentrations in radish and Chinese cabbage (*Brassica rapa* campestris subsp. Napus var. *Pekinensis* MAKINO) tissues, and reported that Zn and Cu concentrations increased when the soil zinc and copper concentrations increased by manure application. A study by Xiong et al. (2010) revealed that high Cu concentrations of Zn and Cu are found in animal manures. The authors collected 215 samples of animal manure and 210 animal feeds. Their results show that the mean Cu concentrations in pig, cattle, chicken, and sheep manure samples were 399.6, 31.8, 81.8, and 66.85 mg kg^{-1}, respectively. Nicholson et al. (1999) studied 183 livestock feeds and 85 animal manure samples collected from commercial farms in England and Wales to determine their heavy metal (Zn, Cu, Ni, Pb, Cd, As, Cr, and Hg) contents. Pig manures generally contained 500 mg Zn and 360 mg Cu kg^{-1}. Typical concentrations in poultry manures were 400 Zn and 80 mg Cu kg^{-1}; cattle manures contained 180 Zn and 50 mg Cu kg^{-1}. Zhang et al. (2005) evaluated heavy metal contents (Cu, Zn, As, Cr, Cd, and Pb) in animal feeds and manures: 104 livestock feeds and 118 animal manure samples from farms of different herd sizes located in northeast China were collected, and their heavy metal concentrations were determined. Cu, As, and Cd contents ranged from 2.3–137.1, 0.02–13.03 mg kg^{-1}, and non-detectable -31.65 mg in pig feeds, 2.88–98.08 mg Cu, 0.02–6.42 mg As, and non-detectable –8.00 mg Cd kg^{-1} in poultry feeds. Their contents in cattle feeds were similar to those of poultry feeds. The typical contents in pig manure were 642.1 mg Cu, 8.6 mg As, and 15.1 mg Cd kg^{-1}, which reflected the metal contents of the feeds. The typical contents in poultry manures were 65.6 mg Cu, 3.3 mg As, and 1.6 mg Cd kg^{-1}, whereas the contents in cattle manures were 31.1 mg Cu, 2.5 mg As,[1] and 0.5 mg Cd kg^{-1}. The heavy metal contents of animal manures are largely a reflection of their content in the feeds consumed and the efficiency of feed conversion by the animals. Sager (2007) reported that mean Cu in pig manure was 282 mg kg^{-1} in Austria. Similarly, a survey of manures in England and Wales generally found a typical content was 350 mg kg^{-1} in pig slurry. However, Dong et al. (2008) found a much higher mean Cu concentration of 1,018 mg kg^{-1} in pig manures from pig farms in Hangzhou, a large city in the Yangtze River Delta, China. Li et al. (2007) reported that the average Cu level in manures from Beijing was 887 mg kg^{-1} in grower-finisher pig manures, which was higher than those from mid- and large-sized pig farms, but lower than that from small farms. In Northeast China, small farms are widely distributed in rural areas, and heavy metal additives are abused in feeds due to insufficient government supervision and lack of professional knowledge. As a result, excessive application of Cu additives to feeds results in high Cu residues in manures from small pig farms. The application of As additives in animal feeds resulted in various As residues in manures (Jackson et al., 2003; Li and Chen, 2005). In England and Wales, the average As contents in pig, layer hen, and cattle manure were 1.68, 1.46, and 0.44 mg kg^{-1} (Nicholson et al., 1999). Sager (2007) reported that the average As content in pig and cattle manure was <1.0 mg kg^{-1} in Austria. Both results are significantly lower than those found in the Northeast China study. However, Jackson et al. (2003) reported that the mean content of As in chicken manure was 15.7 mg kg^{-1} in Alabama, Georgia, and South Carolina, USA. Yao et al. (2006) and Li and Chen (2005) also found a much higher content of As in pig manure: 89.3 mg/kg in Guangdong province and 19.7 mg kg^{-1} in Beijing, which are both areas developed for livestock husbandry. Li and Chen (2005) further suggested that As content in pig manure was greatly enhanced by increasing arsenic levels in pig feed. In terms of average contents, pig and chicken manures contain higher Cd levels than cattle manure (Li et al., 2010), which is consistent with the present study. According to a report by Sager (2007), the mean content of Cd in chicken manure and pig manure in Austria was <0.5 mg kg^{-1}, which is comparable to a survey of chicken manures in the USA (Jackson et al., 2003). In surveys of chicken and pig manures in Beijing and Fuxin, Cd content in Chinese manures were much higher than the above-

Table 1 Heavy metal contents and their sources in various countries

Country	Source	Heavy metal content (mg kg^{-1})					Reference
		Cd	Cu	Ni	Pb	Zn	
Korea	Composted swine manure	1.1	466	11	38.2	566	Ko et al., 2008
	Composted cow manure	0.5	10	4	21	21	Tripathy et al., 2008
Spain	Composted cattle manure	0.8	35	-	9.8	142	Ramos, 2006
	Poultry		14	37	18	94	Ayuso et al., 1996
	Cow	<0.2	<3	3	<3	28	García-Gil et al., 2000
	Cow	<0.5	26	-	9	12	Clemente et al., 2007
UK	Dairy cattle farmyard	0.38	97.5	3.7	3.61	153	Nicholson et al., 1999
	Dairy cattle slurry	0.33	62.3	5.4	4.87	209	
	Beef cattle farmyard	0.13	16.4	2.0	1.95	81	
	Beef cattle slurry	0.26	33.2	6.4	7.07	133	
	Pig farmyard	0.37	374	7.5	2.94	431	
	Pig slurry	0.30	351	10.4	2.48	575	
	Turkey litter	0.42	96.8	5.4	3.62	378	
	Layer manure	1.06	64.8	7.1	8.37	459	
Canada	Poultry	0.48	54.3	7	2.3	550	Ihnat and Fernandes, 1996
	Poultry	<1	160	12	<20	550	Charest and Beauchamp, 2002
	Broiler litter	<1	47	<10	<20	280	
China	Composted manure	1.65	143	-	26.1	475	Wong et al., 1999
Italy	Farmyard	6.0	66	14	60	340	Saviozzi et al., 1999
Venezuela	Goat	1	13	4.4	3.7	71	Acosta et al., 2003
Austria	Cow	0.27	51	6.3	4.1	164	Sager, 2007
	Pig	0.46	282	12.5	1.9	1.15	
Chile	Trout	1.13	33.4	4.94	5.54	605	Salazar and Saldana, 2007
Tunisia	Cow	0.7	26	22	10	120	Achiba et al., 2009
	Farmyard	2.10	25.50	22.40	8.90	117	Cherif et al., 2009
	Poultry	<4	34	<88	<44	75	Hachicha et al., 2009
Malaysia	Chicken	0.5	330	-	1.3	635	Haroun et al., 2009

mentioned results; however, the median content of pig, chicken, and cattle manures was <0.3 mg kg^{-1}. The average Cd contents in pig, chicken, and cattle manures were very high due to the extremely high values found in this survey, such as 203.40 mg/kg in a pig manure sample. Extremely high values of Cd in pig manures have been reported in other areas of China: e.g., 129.8 mg kg^{-1} in Beijing and 120.1 mg/kg in Jilin province (Zhang et al., 2005; Xiong et al., 2010). In actual, the limit of Cd content for the land application of animal manure should follow the requirements of GB8172-87 (Cd <3.0 mg kg^{-1}) in China and Zhang et al., (2005), reported 10 of 118 manure samples collected for their study exceeded the limit. Specifically, the Cd content in an 11.1% pig manure sample, a 11.7% chicken manure sample and a 4.3% cattle manure sample exceeded the limit. In the study of Xiong et al. (2010), there were significant correlations between Cd concentrations in the feeds and manures of pigs, dairy cows, and chickens. Therefore, the addition of Cd to animal feeds, especially pig and chicken feeds, results in high Cd residues in manures, which would pose a high Cd pollution risk to farmlands in Northeast China. The contents of heavy metals in other countries are listed in Table 1.

To deal with large amount of livestock manures, livestock producers store them in piles or lagoons, and manage them to decrease nutrient and pathogen concentrations (i.e. composting) or spread or inject them into the soil to meet the nutrient requirements of crops. Feces are also directly deposited onto land within outdoor pens and pastures. Because animal feces can harbor human pathogenic microorganisms, pathogen transmission from livestock manure to water sources (ground, irrigation, surface, and recreational waters) and food (contamination of food animals and crops) from direct deposition, water runoff events or other routes increases risks to human and animal health. Waterborne disease outbreaks in the United States have been associated with precipitation events (Curriero et al., 2001). Rainfall runoff may carry human pathogens in water runoff from contaminated sites, such as manure-applied land, to bodies of water serving as recreational, irrigation or drinking water. With increasing heavy rainfall events in the United States (Easterling et al., 2000a; b),

Table 2 List of pathogens and their manure sources

Pathogen	Manure Source	References
Bacillus anthracis	goats, others	Sobsey et al., 2006
Brucella abortus	cattle	Sobsey et al., 2006
Campylobacter spp	poultry, cattle	Hrudey et al., 2003
Clostridium botulinum	poultry, swine, cattle	Sobsey et al., 2006
Clostridium perfringens	poultry, swine, cattle	Sobsey et al., 2006
Cryptosporidium parvum	cattle	Atherholt et al., 1998
E. coli 0157:H7	cattle	Nicholson et al., 2005
Erysipelothrix rhusiopathiae	swine	Sobsey et al., 2006
Giardia lamblia	cattle	Kistemann et al., 2002
Leptospira interrogans	poultry, swine, cattle	Sobsey et al., 2006
Listeria monocytogenes	cattle, poultry	Quessy et al., 2005
Salmonella spp	poultry, swine, cattle	Quessy et al., 2005
Yersinia enterocolytica	swine	Quessy et al., 2005

rainfall runoff from manure-applied land reaching to water supplies is a growing concern. In fact, in May 2000, runoff from a field treated with cattle manure contaminated a groundwater supply with human pathogenic bacteria. Common pathogenic bacteria in livestock manure and its sources are listed in Table 2. *Escherichia coli* O157:H7 and *Campylobacter jejuni* were the etiological agents identified in this water-borne outbreak, which sickened 2,300 people and resulted in 7 deaths (Hrudey et al., 2003). In addition to human pathogenic *E. coli* and *Campylobacter*, and other manure-borne pathogens can survive in livestock manure. For example, human pathogenic protozoa *Giardia lamblia* and *Cryptosporidium parvum* can also be focally excreted by infected livestock as well as disseminated by rain runoff events (Atherholt et al., 1998; Tate et al., 2000; Kistemann et al., 2002). Compounding this issue, these manure-borne protozoan parasites are infectious at very low doses (Smith, 1993) and may be able to survive in manure and surface water for long periods (Deng and Cliver, 1992; Fayer et al., 2000; Jenkins et al., 2002). Runoff from livestock-agricultural areas has been reported as an important source of microbial contamination of water bodies. Studies involving fecal bacterial contamination in streams near dairy farms and cattle pastures (Gary et al., 1983; Niemi and Niemi, 1991), surface runoff from grazed pastures (Doran and Linn, 1979; Jawson et al., 1982), and subsurface runoff from manure-applied fields (Culley and Phillips, 1982) have demonstrated the ability of rain water runoff to horizontally transport focally-derived bacteria from manure-laden land to surface water sources. Rain events can also flush manure-borne bacteria vertically, contaminating shallow groundwater (McMurry et al., 1998), as well as springs and wells located within the hydrological catchments of pastures (Howell et al., 1996). In addition to indicators of fecal pollution, manure-borne protozoan pathogens have been released into surface waters in close proximity to manure-applied fields. Because the majority of manure-borne protozoan parasites are transported in the aqueous phase of runoff (Mawdsley et al., 1996), high concentrations of infectious protozoa present on manure-applied cropland have serious human health implications. Sischo et al. (2000) suggested that increased manure spreading frequency and the duration of rain events are risk factors for manure-borne protozoan parasite contamination of surface water. A large proportion of *Cryptosporidium* oocysts that were inoculated into fecal pats were flushed during the first two rainfall events following manure application to rangeland plots (Tate et al., 2000). Limited information, however, is available regarding naturally occurring *Giardia* and *Cryptosporidium* concentrations transported in rainfall runoff from manure-applied cropland. Studies by Nicholson et al. (2005) provided valuable data on pathogen survival during manure storage and following land application under UK field conditions. *E. coli* O157, *Salmonella*, and *Campylobacter* survived in stored slurries and dirty water for up to three months, with *Listeria* surviving for up to six months. The timing of manure spreading throughout the year is important. Manure will gradually decompose in the soil zone. As decomposition occurs, nutrients from the manure become available for use by the plant. Manure contains a large number of microorganisms; very few are pathogenic microorganisms that can spread disease to humans. The easiest mode of transfer of pathogens from animals to humans is through direct contact. Quessy et al. (2005) reported that microorganisms such as *Salmonella*, *Yersinia enterocolitica*, *Listeria monocytogenesis*, and *Cryptosporidium* in cattle, poultry, and swine manure are able to survive in typical storage conditions used on livestock farms, and most of these organisms can be detected in the soil following land application of the manure. However, upon harvest, the authors did not detect any microbial contamination of root and leaf vegetable crops that had been fertilized with manure. The potential for disease transmission is very low, because pathogens are rapidly destroyed by drying and exposure to sunlight.

This article highlighted the risks associated with heavy metals and pathogenic microorganisms in livestock manure. Managing livestock manure is an important environmental concern. Manure is a good source of major plant nutrients such as nitrogen, phosphorus, and potassium, as well as other secondary nutrients that plants require; however, to maintain a sustainable agriculture practice, the excess nutrients should be removed from the livestock manure first, and then can be used as a fertilizer. Livestock manure management and treatment technologies should be able to efficiently remove or minimize the pathogens and heavy metals in order to prevent human and animal exposures to those that would pose health risk. Novel technologies such as fluidized bed biological reactors, intermittently aerated sequencing batch reactor, autothermal thermophilic aerobic digestion can be introduced to remove excess nutrients, toxic heavy metals, and, pathogenic bacteria from the livestock manure before application to the agriculture fields.

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