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ORIGINAL ARTICLE

Environmental pollution induced by heavy metal(loid)s from pig farming

Zemeng Feng[1,2,3,4,7] · Hanhua Zhu[1,2,3,4] · Qifeng Deng[1,2,3,4,5] · Yumin He[1,2,3,4,6] · Jun Li[1,2,3,4,6] · Jie Yin[1,2,3,4] · Fengxian Gao[5] · Ruilin Huang[1,2,3,4] · Tiejun Li[1,2,3,4,7]

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Abstract

The development of intensive and large-scale livestock farming, such as pig husbandry, is significantly increasing the amount of manure globally. Mineral additives are commonly used in animal feed, and heavy metal(loid)s (HMs) are introduced to the feed via incomplete purification processes of those mineral additives, which leads to inevitable environmental pollution by HMs in conjunction with manure production. When these toxic-metal-containing manures are used as fertilizer, the HMs accumulate in soils and crops, which further causes potential risks to human health and the ecological environment. In this review, the focus is on seven HMs that are related to human activities or frequently contained in animal feed, including copper, zinc, cadmium, chromium, lead, mercury, and arsenic. The toxicities of these HMs and the elimination methods to reduce the HM toxicity of pig manure when it is added to soil, i.e., liquid–solid separation, adsorption, bioleaching, and composting, are summarized. The ultimate aim of this review is to outline the systematic pollution management strategies for HMs from pig farming.

Keywords Pig manure · Heavy metal(loid)s · Pollution · Pig farming · Soil amendment

✉ Zemeng Feng
zemengfeng2006@163.com

✉ Tiejun Li
tjli@isa.ac.cn

1 Key Laboratory of Agro-ecological Processes in Subtropical Region, Institute of Subtropical Agriculture, Chinese Academy of Sciences, Changsha 410125, Hunan, China

2 National Engineering Laboratory for Pollution Control and Waste Utilization in Livestock and Poultry Production, Changsha 410125, Hunan, China

3 Hunan Provincial Engineering Research Center for Healthy Livestock and Poultry Production, Changsha 410125, Hunan, China

4 Scientific Observing and Experimental Station of Animal Nutrition and Feed Science in South-Central, Ministry of Agriculture, Changsha 410125, Hunan, China

5 College of Animal Science and Technology, Hunan Agricultural University, Changsha 410128, Hunan, China

6 Animal Nutrition and Human Health Laboratory, School of Life Sciences, Hunan Normal University, Changsha 410081, China

7 Hunan Co-Innovation Center of Animal Production Safety, Changsha 410128, Hunan, China

Abbreviations

HMs	Heavy metal(loid)s
dm	Dry matter
PM	Pig manure

Introduction

Intensive and large-scale livestock farming has largely developed over the past few decades (Su 2006). Mineral additives are commonly used in animal feed to satisfy mineral requirements and improve the growth performance of livestock. Mineral elements, such as copper, zinc, iron, chromium, manganese, and cobalt are essential for livestock. Owing to the low purity of mineral additives used in animal feed, non-essential trace elements, such as cadmium, mercury, arsenic, lead, and other heavy metal(loid)s (HMs) are introduced into livestock farming (Nies 1999; Hill et al. 2000). Only small amounts of HMs in feed are actually absorbed by the animals; most are excreted in the feces (Cang et al. 2004). In pigs, the absorption rates of Cu and Zn are only 10–20%. The unutilized HMs accumulate in the animal manure. Levels of HMs in pig manure (PM) have been measured at 151.11 mg/kg Cu, 538.29 mg/kg Zn, 10.64 mg/kg Cr, 9.27 mg/kg Ni, 1.56 mg/kg As, 2.12 mg/kg Pb, 1.95 mg/kg Se, and 0.27 mg/kg Cd dry matter (DM) (Ciraj et al. 1999; Ito et al. 2001; Zhou et al. 2015). The HMs in animal manure have led scientists and the general public to worry about the potential risks to soils and food safety when animal manure is used directly in agriculture (Cang et al. 2004).

An estimated 618 billion kilograms of PM is produced (Hao et al. 2006), and most of it is used as a soil fertilizer owing to its benefit of richness in nitrogen, phosphorus, and organic materials, which help to improve plant growth and the physical and chemical properties of soil (Dao and Schwartz 2010). However, direct manure application also causes potential environmental problems (Nies 1999; Hill et al. 2000). In China, the major cause of HMs pollution of croplands is the use of HM-containing fertilizers (Chen et al. 2000). This problem exerts a profound effect on environmental and human health, because HMs can remain in soil for a long time. For example, the levels of Cu and Zn in soil are reduced by only 16 and 19%, respectively, 10 years after PM use is ceased (Kwon et al. 2014). In addition, HMs accumulated in soil can migrate to surface waters and groundwater, which further negatively affect water quality and human health (Kwon et al. 2014). More than 12 million tons of HM-polluted crops have been produced, which has led to an annual economic loss of over 20 billion Chinese RMB (Kwon et al. 2014). Dietary HM-polluted crops may be carcinogenic, nephrotoxic, neurotoxic, and teratogenic, and can induce immunosuppression, cardiovascular, and pulmonary diseases and impaired reproduction (Cooksey 2012; Sethy and Ghosh 2013; Rana 2014; Sfakianakis et al. 2015). Therefore, the application of PM to agricultural land should be supervised (Zhang et al. 2014).

Another negative characteristic of HMs is their association with antibiotic resistance. PM is a reservoir of antibiotic resistance genes (ARGs), which are positively related with the concentrations of both antibiotics and HMs (Lu et al. 2017). HMs such as Cu and Zn and their derivative chemical compounds exhibit antimicrobial activity (Zhang et al. 2014). Prolonged use of these mineral additives imposes a strong and long-lasting selection pressure on microbes and induces an increase in ARGs (Ji et al. 2012). Significant positive correlations have been found between typical HMs and some ARGs, particularly among *Salmonella* serotypes, which is an important issue in public health (Zhu et al. 2013). Some *Salmonella* strains have been shown to be resistant to HM micronutrients, including Cu and Zn (Zhang et al. 2014). Such resistant strains carry genes associated with multiple antimicrobial resistance factors (Ciraj et al. 1999). Mercury is associated with the methicillin resistance of *Staphylococcus aureus*, which has been the major cause of hospital-acquired infections for nearly 50 years (Ito et al. 2001), whereas Cu is specifically associated with resistance to vancomycin (Zhang et al. 2014). Levels of Cu, Zn, and Hg are strongly correlated with *Sul*A and *Sul*III. HMs also have significant combined effects on the efficacy of antibiotics. The antibiotic resistance of bacteria is affected by the type and concentration of co-exposure to HMs (Zhou et al. 2015). It is most noticeable in the cross-resistance to Hg and antibiotics. The resistances to Hg and cefradine or amoxicillin; and to Cr and amoxicillin were synergistic for low HM concentrations, but became antagonistic with increasing concentrations, whereas the resistances to Cr or Cu and cefradine, Pb or Cu and amoxicillin, and Cu and norfloxacin had the opposite pattern. The resistance to Zn and amoxicillin was always synergistic, whereas the resistance to Pb and cefradine or norfloxacin, Cr or Hg and norfloxacin, and all the HMs and tetracycline were antagonistic.

This review summarizes the literatures on seven typical HMs, i.e., Cu, Zn, Cd, Cr, Pb, Hg, and As. These HMs were selected because they are frequently related to human activities or commonly introduced into animal feed through mineral additives (Chen et al. 2009). The ultimate aim of this review is to outline a HM pollution management system in order to promote the sustainable development of pig farming.

Typical HMs used in pig farming

Cu

Cu is an essential trace element that plays an important role in plant, animal, and human nutrition. It is needed to activate several oxidative enzymes, and is required for metabolic balance (Chen et al. 2009). High-dietary Cu promotes pig growth, a phenomenon has been well studied since 1945 (Armstrong et al. 2004; Yang et al. 2012). The mechanism of this promotion may be related to the bacteriostatic activity, feed intake increase, enzyme activity enhancement, and neuropeptide release induced by Cu (Puig and Thiele 2002). At a suitable concentration, Cu can improve the growth of microorganisms and their capacities to transform and exploit carbon sources in the form of polymers, thus promoting agricultural waste decomposition. However, high Cu concentration would extend this process, which can be explained by the connection between the Cu concentration and enzyme activities (Guo et al. 2012; Azarbad et al. 2013). Cu is more toxic than Zn toward soil–microbial catabolism of polycyclic aromatic hydrocarbons (Obuekwe and Semple 2013). Cu is highly toxic to *Gobiocypris rarus* and zebrafish embryos (Zhu et al. 2014; Li et al. 2015), and increases sensitivity in the early developmental stages of Atlantic salmon (Mahrosh et al. 2014). Excessive Cu can also harm livestock and humans (Uauy et al. 2008).

Zn

Zn is another essential trace mineral that plays a significant role in metabolism as a component of more than 300 metallo-enzymes and transcription factors (Hambidge 2000). Zn improves intestinal mucosal integrity and the absorption of water and electrolytes (Ghishan 1984); enhances the performance of weaned piglets by increasing their daily feed intake, growth rate, and feed conversion (Zhang and Guo 2009); and prevents enteric infection and diarrhea (Ghishan 1984). It is the most widely studied alternative to growth-promoting antibiotics (Ghishan 1984). However, the abuse of Zn increases both the diversity of *E. coli* clones in livestock and the proportion of multi-drug-resistant *E. coli* strains (Bednorz et al. 2013). The resistance to Zn was largely confined to *Enterococcus faecalis* (Fard et al. 2011). Excessive concentrations of Zn adversely affect soil microorganisms and *Gobiocypris rarus* embryos (Azarbad et al. 2013; Zhu et al. 2014).

Cd

Generally, the background level of Cd in soil in China is relatively low (about 0.1 mg/kg) (Chen et al. 2004). Atmospheric deposition and fertilization use may be the primary influences on the Cd content of soil (Satarug et al. 2003). A previous study considered Cd pollution and toxicity from a global perspective (Satarug et al. 2003). Cd is often present in mineral supplements with Zn and phosphates as an impurity. Added zinc sulfate and phosphate were the main sources of Cd in animal compound feeds in Guangxi, Hubei, and Hunan, three provinces in China; e.g., Zn sulfate additives contained 1.0–3.6% Cd (Satarug et al. 2003). About 5% of purchased premixed pig feeds contained 150–370 mg/kg Cd, whereas 73.6 mg/kg Cd was observed in home-mixed feeds. A pig body only assimilates a small amount of the Cd in feed; most is excreted in the feces. The concentration of Cd in PM was positively correlated with that in feed. Samples of PM collected in Jilin province contained a mean of 59.66 mg/kg Cd with a wide range of 0.25–120.13 mg/kg (Satarug et al. 2003). About 51.7% of the commercial organic fertilizers made from PM in China had Cd levels that exceeded the limitation, with the highest value being 42.7 mg/kg (Satarug et al. 2003). PM is an important contributor to soil Cd of Beijing and Fuxin farmlands (Li et al. 2010). In addition, Cd is often detected in vegetables and some animal haslets at levels above the national food hygiene standards of China (Satarug et al. 2003). Transfer of Cd from the soil to edible parts of crops (rice and/or wheat products) is an important pathway that leads to human exposure to Cd (Brus et al. 2009). After dietary exposure, Cd is efficiently retained in the human kidney and liver and has a very long biological half-life ranging from 10 to 30 years (Satarug et al. 2003).

Cd is classified as a category I carcinogen in humans according to the International Agency for Research on Cancer, and Cd exposure can result in various medical abnormalities including mutagenesis, teratogenesis, and carcinogenesis (Waalkes 2003; Huff et al. 2007). Cd also affects the growth of livestock, as it decreases the average daily feed intake and increases the feed/gain ratio in pigs (Du et al. 2013). In addition, Cd is associated with oxidative stress in adults (Waalkes 2003; Huff et al. 2007); and is highly oxic to embryos (Zhu et al. 2014; Warren et al. 2000) and ostracods (Sevilla et al. 2014). Cd is more toxic than most of HMs, with bound cation toxicity in the order H $<$ Al $<$ (Cu, Zn, Pb) $<$ (Cd, Ag) (Tipping and Lofts 2015). Cd adversely affects biological systems in various ways and targets the kidneys, liver, vascular system (Waalkes 2003; Huff et al. 2007), bones, and reproductive system (Waalkes 2003; Huff et al. 2007; Zhang et al. 2008; Kim et al. 2009; Acharya et al. 2008; Angenard et al. 2010). Various strategies have been developed to mitigate the toxicity of Cd in animals (Renugadevi and Prabu 2010; Lacorte et al. 2013).

Cr

Cr plays a role in normalizing carbohydrate, lipid, and protein metabolism in humans and animals (Mertz 1993; Cefalu et al. 2002; Bernao et al. 2004). The primary metabolic role of Cr is to enhance insulin function by facilitating the binding of insulin to receptors in the cell wall (Anderson et al. 1997). The effects of Cr(III) in different chemical forms on the growth, carcass characteristics, immune function, reproduction and tissue deposition of livestock have been well studied (Lindemann et al. 1995; Shelton et al. 2003). These forms contain chromium picolinate (Kim et al. 2009), $CrCl_3$ (Kim et al. 2009), chromium nicotinate (Kegley et al. 1996), and chromium propionate (CrProp) (Shelton et al. 2003), chromium tripicolinate, chromium-L-methionine, $CrCl_3$, and chromium nanocomposite. All of these can benefit the growth performance of piglets, with chromium nanocomposite showing a greater effect (Kim et al. 2009). Dietary supplemental chromium-loaded chitosan nanoparticles have significantly increased the contents of Cr in blood, muscle, and selected organs, including the heart, liver, kidney, and pancreas (Wang et al. 2012). Organic Cr(III) is thought to have greater biological availability than inorganic Cr(III) (Kim et al. 2009).

Pb

Pb is accumulated at a high rate in the kidney of animals and humans (Chen et al. 2012; Suksabye et al. 2007). In wild boars, the Pb concentrations in the liver and kidneys were approximately the same, but much higher than that in the muscles (Suran et al. 2013). Pb significantly reduces gonadotropin binding and alters steroid production in vitro (Priya et al. 2004; Nampoothiri and Gupta 2006). During lactation, Pb is excreted into the milk (Namihira et al. 1993; Hallen et al. 1995). Pb also can accumulate in the fetus from the second trimester onward (Bhattacharyya 1983). Furthermore, Pb(II) induces deformity and cardiovascular toxicity in zebrafish embryos (Li et al. 2015). The contamination source of Pb in animal farming has been traced back to the zinc oxide used in early post-weaning (Dj et al. 2015).

Hg

Hg is a potential neurotoxic agent and neurotoxicant (Pugach and Clarkson 2009) that accumulates in human follicular fluid (Al-Saleh et al. 2008) and in the liver, kidney and muscle of pigs (Chen et al. 2012; Suksabye et al. 2007). In wild boars, the highest Hg concentration was measured in the kidneys (Suran et al. 2013). The use of fish meal is the main cause for the increase in levels of Hg in animal tissues (Jorhem et al. 1991). Animals (especially ruminants) that are fed fish meal can bioconcentrate monomethyl mercury in protein matrices, including eggs, meat, and dairy products (Dórea 2006).

As

As is a metalloid that is present in both inorganic and organic forms with different oxidation states (− 3, 0, + 3, + 5) (Hughes 2002). A trace amount of As is essential for animal growth, as a deficiency of As will cause abnormal reproduction (impaired fertility and increased perinatal mortality) and depressed growth (Uthus 1992). Myocardial damage and changes in mineral concentrations in various organs have also been noted in As-deficient animals. Organoarsenics (such as roxarsone and arsanilic acid) are widely used as excellent feed additives in animal production worldwide, which also introduces As impurities to feeds (Wang et al. 2017). As(III) and As(V) were the two most commonly detected As impurities in feeds bearing organoarsenicals. The widespread use of As in feed additives pollutes the soil with As via animal waste from concentrated animal-feeding operations (Liu et al. 2015). The trivalent and pentavalent oxidation states of As have toxic effects; exhibiting neurotoxicity, nephrotoxicity, hepatotoxicity, and reproductive toxicity (Das et al. 2005; Tyler and Allan 2014). The relative toxicity order of As is iAs(III) > monomethyl arsine oxide (MMAO(III)) > DMA arsenotriglutathione (DMAIIIGS) > DMAV > MMAV > iAs(V) (Vega et al. 2001; Hindmarsh and Mccurdy 1986). Inorganic As compounds are carcinogenic; and more hazardous than organic compounds (Bustaffa et al. 2014). For As(III) and As(V), 90.8 ± 12.4 and 85.0 ± 19.2%, respectively, of the oral intake dose was absorbed by the gastrointestinal tract, whereas organic As was poorly absorbed, resulting in low bioavailability values from 20.2 ± 2.6% (monomethylarsonic acid) to 31.2 ± 3.4% (dimethylarsinic acid) (Islam et al. 2017).

Potential methods for controlling HMs in pig farming

Animal manures are widely applied to soil as fertilizers, a practice that may lead to the accumulation of HMs in soil and pose health risks (Liu et al. 2015). These HMs are expected to move up the food chain and harm livestock, and ultimately humans. Metals (mainly Cu and Zn) are present in either organic matter or inorganic particulates (Marcato et al. 2008), with approximately 80% of Zn and over 95% of Cu associated with particles 0.45–10 μm in diameter (Liu et al. 2015). The HMs in PM can be divided into five fractions: exchangeable, carbonate bound, Fe–Mn-oxide bound, organic matter bound, and residual fractions (Liu et al. 2015), with the first three fractions considered bioavailable (Morera et al. 2001). In fresh PM, Zn is mainly present in the form of Fe–Mn oxides, Cu is mainly bound to organic matter, and Mn is mainly present in the Fe–Mn oxides, carbonates bound, and residual forms. Nonlinear regression analysis revealed a positive logarithmic relationship between the bioaccumulation factors and the exchangeable metal concentration of PM (Li et al. 2010). The bioavailability of HMs in PM can be altered by either regulating the PM characteristics, such as the pH and organic matter content, or adding additives such as fly ash (Liu et al. 2015). Composting, anaerobic digestion, and other methods are often used to treat livestock slurry, but these procedures do not reduce the total content of metals (Marcato et al. 2008; Guerra-Rodriguez et al. 2006).

The most common and simple pretreatment for PM is liquid–solid separation, for which the largest proportion of extractable metals are still in the residual form in both the solid and liquid portions. The Cu and Zn in activated sludge effluent are soluble, and the concentrations of Cu and Zn in the effluent are sufficiently low, and in soluble form. Separation is important for the removal of Cu and Zn, with 96 and 95% of the total Cu and Zn removed, respectively (Suzuki et al. 2010). It is different for the load amounts of Cu and Zn when the solid and liquid fractions are utilized as crop fertilizer (primarily as P fertilizer). The load amounts of Cu and Zn added from the solid fraction to the soil do not differ markedly from the loads applied with the addition of raw PM, while that are markedly lower from liquid fraction produced by optimized separation treatments that included flocculation and coagulation (Popovic et al. 2012). There is a linear correlation or a positive linear relationship between the removal of these HMs in suspended solid versus solid form. The commonly used separation treatments including polymer flocculation and drainage, coagulation with iron sulfate addition and polymer flocculation plus drainage, ozonation and centrifugation, centrifugation only, and natural sedimentation. A previous study compared the applied effects of these five treatments on PM (Popovic et al. 2012). Total Cu and Zn were separated with greater efficiency when following chemical pretreatment with flocculants and then introducing coagulants before mechanical separation at both commercial and laboratory scales. The use of flocculant increased the amounts of bioavailable metals (water soluble and exchangeable) partitioned into the solid separate. The application of separated liquids obtained from a rotary press with flocculant and the separation of flocculants could minimize metal loading amounts to farmlands (Marcato et al. 2008; Guerra-Rodriguez et al. 2006).

Physical methods are also available ways to treat HM pollution. Addition of biochar derived from orchard prune residue can decrease the bioavailability of Cd, Pb, Ti, and Zn in mine tailings (Fellet et al. 2011). Soil amended with rice-straw-derived biochar showed increased Pb adsorption capacity (Jiang et al. 2012). The addition of oxidized biochar to soil significantly improved Pb, Cu, and Zn stabilization (Uchimiya et al. 2012). PM-derived biochar produced at 450 °C could serve as a potential amendment for the immobilization of HMs in sandy soil (Xu et al. 2014). Biochar made at 400 °C from PM that was aerobically composted for 84 days has been used as an adsorbent for the removal of HM ions from wastewater (Marcato et al. 2008; Guerra-Rodriguez et al. 2006). With focus on the minimization of environmental pollution of HMs in PM, 700 °C is the preferred pyrolysis temperature for the conversion to biochar of PM contaminated with HMs (Meng et al. 2017). Biochars derived from tomato green waste and chicken manure were more effective in reducing Cd mobilization in soil, by 35–54 and 26–43%, respectively, to ensure food safety and in reducing Cd accumulation in shoots of pak choi cultivars by 34–76 and 33–72%, respectively, in a low Cd accumulator cultivar and by 64–85 and 55–80%, respectively, in a high Cd accumulator cultivar compared to the control (Yasmin et al. 2017). Mushroom biochar addition reduced total arsenic and the percentage of bioavailable arsenic more than addition of rice-straw biochar did (Cui et al. 2017). Hexavalent chromium (Cr(VI)) can have a strong adverse impact on the environment and must be removed from any waste before it is discharged (Kim et al. 2009). Numerous by-products of plants and animals, including coir pith, cow bone, bamboo charcoal, corn stalks, and palm shells, have been used to prepare activated carbon to absorb Cr(VI) (Chen et al. 2012; Suksabye et al. 2007). Pig bone can be used to produce a hierarchical porous carbon (HPC), which strongly adsorbes Cr(VI), with some of the Cr(VI) reduced to Cr(III) on the adsorbent surface. The maximum Cr(VI) adsorption capacity of HPC reported is 398.40 mg/g at pH 2. The HPC showed an adsorption capacity of 92.70 mg/g even after the fifth adsorption cycle (Marcato et al. 2008; Guerra-Rodriguez et al. 2006). Various other adsorbent materials have been developed to remove Cr(VI) from wastewater, including activated carbon, fibers, polymers, and reverse osmosis membranes (Jusoh et al. 2011). Soluble or colloidal organics derived from animal excreta are able to mobilize metals, enhance the risk of HM leaching, and possibly reduce groundwater quality (Marcato et al. 2008; Guerra-Rodriguez et al. 2006). Amendments led to a rapid decrease in exchangeable metal concentrations, except for Cu, with decreases of up to 98, 75, and 97% for Cd, Pb and Zn, respectively. Maifanite can lower the level of Cd when it is added to Cd-contaminated diets (Du et al. 2013). The addition of zero-valence iron decreased the bioavailability of Cu and Zn in solid digested residues (Liang et al. 2017). Ca-bentonite could restrict the mobility and accumulation of Cu and Zn in plants (Wang et al. 2017). The combined addition of marble waste and PM produced the greatest reduction in metal concentrations (Zornoza et al. 2013). The order of treatment efficacy in the reduction of extractable Cu and free Cu(II) in low-pH soils ($pH < 5.5$) was 2% mica > 1% mica > 2% montmorillonite > 0.1% mica. At 120 days, treatment with 2% mica maintained a reduction in free Cu(II) activity of up to 93% and in the extractable Cu concentration of up to 75% upon acidification, compared to the original soil pH value. In addition, Cu retention in mica-treated soils was more resistant to acidification than that in lime-treated soils. This mica keeps promise for the remediation of acidic soils with metal contamination at the surface (Stuckey et al. 2008). Soil amendment with rice straw increased the Cu and Zn concentrations in earthworms and increased the concentrations of available Cu and Zn (Zhu et al. 2014).

The biosorption of HMs by bacteria and fungi has also been reported. Cd(II) was bound by *Candida tropicalis* CBL-1 and *Staphylococcus aureus* (Rehman et al. 2010; Nikolic et al. 2015). *Weissella viridescens* MYU 205 decreased Cd(II) levels in citrate buffer (pH 6.0) from 1 ppm to about 0.46 ppm, corresponding to 10.46 µg of Cd(II). Hg(II) was bound to many bacterial cell surface proteins of *W. viridescens* MYU 205, and a ~ 14 kDa protein with a CXXC motif may have contributed to this function. *Bacillus megatherium* D01 was found to bind Au(III) and Pt(IV). *Bacillus cereus* showed resistance and biosorption to Ag(I) (Nikolic et al. 2015). HMs were adsorbed by lactic acid bacteria (Schut et al. 2011), most strongly Hg(II), followed by Pb(II) and As(III), and these may contribute to the detoxification of people exposed to HMs (Kinoshita et al. 2013).

Physical separation and absorption are forms of pretreatment, but further treatments are needed to transform HMs in the PM to more stable forms that cannot be absorbed by living things. Some microbes can thrive under conditions of severe HM pollution, because they have unique mechanisms to suit that type of environment. The most common mechanism is the czc operon system, which comprises an efflux protein (CzcA), a cation funnel (CzcB), a modulator of substrate specificity (CzcC) (Nies et al. 1987, 1989; Nies 1992), and a protein involved in regulation of the operon (CzcD). The CzcD gene is involved in the regulation of a zinc, cobalt, and cadmium efflux system, as the czc system mediates resistance to these HM cations (Nikolic et al. 2015). In addition to being able to merely live in a HM-polluted environment, microorganisms can actually change the chemical form of HMs. A bioleaching technique has been developed as an attractive method for transforming HMs from sludge, sediments, and soils into stable forms (Chen and Lin 2004; Fang and Zhou 2007; Pathak et al. 2009), and makes treated PM be applied. Using a mixture of harmless iron- and sulfur-oxidizing bacteria in an air-lift reactor, bioleaching could efficiently remove Zn (95.1%), Cu (80.9%), and Mn (87.5%) from PM. The removal efficiencies are related to the pH and oxidation (Zhou et al. 2012). In successive multi-batch bioleaching systems, co-inoculation of the PM degrader *Galactomyces* sp. Z3 and two *Acidithiobacillus species,* including *Acidithiobacillus ferrooxidans* and *Acidithiobacillus thiooxidans,* could remove Zn and Cu with efficiency exceeding 94 and 85%, respectively (Zhou et al. 2013). Corncob silica combined with alginate and immobilized bacteria (*Pseudomonas putida* YNS1) has been used to remove HMs from contaminated water (Shim et al. 2014). The accumulation of HMs in the above-ground tissues of plants results in an increase in metal accumulation in topsoil, via leaf deposition, or creates an exposure pathway for the introduction of metals into the food chain (Mertens et al. 2004; Unterbrunner et al. 2007). *Thymus mastichina* and *Lavandula stoechas* highly accumulate different metals and metalloids such as Ni, Cr, Co, Mn, Zn, and As, in their above-ground parts (Diez Lazaro et al. 2006).

Composting is a common and effective treatment before agricultural wastes are used as resources (Gabhane et al. 2012), and microbes and their secreted enzymes are involved in this process (Nikolic et al. 2015). HMs can influence microbe reproduction and further affect the bio-disintegration of agricultural wastes (Pages et al. 2007; Rossbach et al. 2000). Whereas Cu can promote enzyme activity by acting as an enzyme cofactor, too much Cu can decrease enzyme activity (Schutzendubel and Polle 2002). The treatment of PM via anaerobic digestion has been reported to increase the bioavailability of Zn (Fard et al. 2011). HMs in compost from soil, groundwater, and plants can be transmitted through the food chain, causing adverse effects on animal and human health (Nikolic et al. 2015). In composting, additives such as mineral nutrients are used to reduce the availability of HMs, enhance microbial activity, facilitate the composting process, and improve compost quality (Himanen and Hanninen 2009). Zeolites could significantly remove Ni, Cr, Pb, Cu, Zn, and Hg (Villasenor et al. 2011). An increase in the proportion of bentonite, up to a maximum of 2.5%, in PM compost can reduce the extractable HM content (Li et al. 2012). Rock phosphate could reduce the availability of metals through adsorption and complexation of the metal ions with inorganic components (Lu et al. 2014). The addition of bamboo charcoal or bamboo vinegar to PM compost is also an effective method for reducing the mobility of Cu and Zn (Chen et al. 2010).

Dissolved organic matter (DOM) can form complexes with HMs and increase their transportation to surface water (Aldrich et al. 2002). Humic and fulvic acids are major components of natural water and represent up to 70% of DOM, which contributes the most organic ligands to Cu complexation (Croue et al. 2003). The ability of DOM from manure to complex with Cu is inhibited because of the reduction in protein-like materials after composting. Composting decreases the bioavailability, mobilization, and transportation of the manure DOM-Cu complexes, lowering the potential risk of pollution in soil and groundwater (Zhang et al. 2012). The fraction in vinasse with the highest proteinaceous fluorescence had the greatest ability to bind with Cu. Nonhumic substances such as amino acids likely play a role in Cu complexation (Nikolic et al. 2015). DOM from both organic wastes and PM contain a large number of proteinaceous materials (Marhuenda-Egea et al. 2007).

Conclusion

The potential harm of HMs from PM in China should not be neglected owing to the huge amount of PM produced annually. This issue has attracted the attention of scientists, and many simple and complicated models have been developed to predict the potential environmental impact of toxic metals in PM (Sheppard et al. 2009). A PM-earthworm system is widely used to pretreat PM in China. Earthworms accumulated HMs when they were exposed to HM-contaminated soil. The variations in Pb and Cd concentrations in *E. fetida* were associated with the exchangeable fraction, that of Cu was associated with the exchangeable and Fe–Mn-oxide-bound fractions, and that of Zn was strongly associated with the exchangeable, carbonate-bound, and Fe–Mn-oxide-bound fractions (Hobbelen et al. 2006). Methods for determining HM levels in compost have also been studied. The nitric acid procedure and dry-ashing methods had been recommended for use in digesting compost (Nikolic et al. 2015). Other studies have focused on how to decrease the toxicity of HMs toward organisms. For example, lipoic acid and glutathione have shown potential for reducing the toxic effects of Pb, Cd and Cu in Wistar rats (Nikolic et al. 2015).

Hopefully, the issue of HM pollution of soil due to the direct use of PM can be resolved through further development of technology and attention from the government.

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Compliance with ethical standards

Conflict of interest All the authors declare that they have no conflict of interest.

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