Bulgarian Journal of Agricultural Science, 18 (No 5) 2012, 733-741
Agricultural Academy

LEACHING AND MOBILITY OF HEAVY METALS AFTER BURNED AND UNBURNED POULTRY LITTER APPLICATION TO SANDY AND MASA SOILS

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Abstract

FARIDULLAH, A. WASEEM, A. ALAM, M. IRSHAD, M. A. SABIR and M. UMAR, 2012. Leaching and mobility of heavy metals after burned and burned poultry litter application to sandy and masa soils. *Bulg. J. Agric. Sci.,* 18: 733-741

Application of poultry litter to cropland may increase metal mobility, because the soluble organic ligands in poultry litter can form water-soluble complexes with metals. The leaching characteristics of soils may be greatly affected by application of burned and unburned poultry manures. Poultry litter and litter ash samples from the Tottori prefecture were collected and analyzed for extractability and mobility of Cu, Zn, Ni and Mn in two Japanese soils in Japan using pot-leaching studies. Packed soil in the pots after receiving burned and burned poultry manure respectively were leached with water. Manure types were differed identically in order of PLA masa> PLA sand > PL masa > PL sand> Control soil. The results suggested that the release potential of Cu and Zn was greater in the PL amended sand and Masa soil than in the PLA amended soils. Mn and Zn leaching from different amendments varied in the order PL masa> PLA masa > PL sand > PLA sand> Control masa> Control sand soil. Where as the concentration of Cu and Ni were observed as PLA masa > PL masa >PLA sand and PL sand exponentially. The application of poultry litter to metal-contaminated soils may influence metal leaching and distribution of metals among soil fractions. The purpose of this study was to quantify the solubility and distribution of heavy metal in poultry wastes amended soils receiving poultry waste applications and their leaching to ground water. The transformation of these metals in the soil was monitored by analyzing the soil samples for concentration of heavy metals.

Key words: leaching, extractability, mobility, heavy metals; soil chemical characteristics, poultry litter ash (PLA)

Introduction

Intensive poultry farms are mostly located in the suburbs of big cities. These produce large amounts of manures, which contain high concentrations of nitrogen and phosphorus, and easily cause environmental problems such as water eutrophication and air or soil pollution (Faridullah et al., 2012; Jafry et al., 2012). The impact of contaminants on the environment should be of scientific concern, in order to minimize the threat of soil and groundwater pollution. Waste disposal on agricultural lands has been increasingly favored lately and, therefore, it should be scrutinized to diminish the risk of introducing pollutants to soils and waters (Ullah et al., 2012; Mahmood et al., 2012). In this context, presence of heavy metals in several wastes used in agriculture today has imposed a need for a better understanding of the processes of soil heavy metal interactions, in particular, their mobility and retention. One of the major problems is the accumulation of large amount

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of wastes, especially manure and litter, generated by intensive production. Large-scale accumulation of these wastes may pose disposal and pollution problems unless environmentally and economically sustainable management technologies are evolved (Sharpley et al., 2007). Poultry litter has been applied to agricultural soils for decades as an organic fertilizer, because it is a good source of plant nutrients. Poultry litter, a combination of excreta, feathers, wasted feed, and bedding materials, is a valuable by-product of poultry production. Poultry waste contains all essential nutrients including micronutrients and it has been well documented that it provides a valuable source of plant nutrients (Chan et al., 2008; Harmel et al., 2009), especially for organic growers and disposal of poultry litter may alter metal status in soil by affecting metal solubility.

The soluble complexes with heavy metals can be transported downward and possibly deteriorate groundwater quality. Addition of poultry manure to soils not only helps to overcome the disposal problems but also enhances the physical, chemical and biological fertility of soils (McGrath et al., 2009). Addition of poultry manure has been shown to improve the fertility of the cultivated soil by increasing the organic matter content, water holding capacity, oxygen diffusion rate and the aggregate stability of the soils (Adeli et al., 2009).

Most of the environmental problems associated with improper practices of land application of manure by-products have centred on the contamination of ground and/or surface water with two major nutrients, N and P (Sims et al., 2005). However, manure by-products may also contain other potentially toxic trace elements, such as arsenic (As), copper (Cu) zinc (Zn), and nickel (Ni) which, to date, have received less attention.

In order to avoid metal accumulation in soil, there are laws or regulations in many countries, which define threshold concentrations and loading rates of heavy metals on agricultural soil to protect the soil environment from potentially detrimental effects. However, of particular importance is the application of poultry litter or sewage sludge to soil, which contains high levels of heavy metals (from either contamination or parent materials). In this case, the soluble organic ligands might increase the migration of metals as organic complexes, and, therefore, deteriorate groundwater quality. Poultry manure is rich in nutrients. The estimates show that if poultry manure is properly managed it can contribute about 101 thousand tones of nitrogen, 58 thousand tones of $P_2O_5$and 26 thousand tones of K_2O (FAO).

In order to understand metal mobilization by soluble organic ligands in poultry litter, leaching experiments were employed to investigate the movement of Zn, Cu, Mn and Ni in Poultry litter and litter ash-amended soils.

Materials and Methods

Poultry litter was collected from Tottori prefecture, Japan. The litter was air dried, crushed and sieved (< 250 micron) to ensure homogeneity. The PL was weighed up to 100g into porcelain crucibles and ashes simultaneously in the muffle furnace at 600^{o}C for 2 h. On removal from the oven, the samples were placed in glass desiccators and allowed to cool for 30 min. The selection of 600^{o}C burning temperature was based on our previous study (Faridullah et al., 2008a), where total extractable P and some other metals fraction was obtained at its highest in the burned poultry litter.

In this study, sandune and masa soil was used. According to the United Soil Classification System of Japan (2002), soil is classified as Sand dune Regosol and masa Terrestrial Regosol. The physicochemical properties of the PL and PLA reported in Table 1 were determined by using the procedures described previously (Faridullah et al., 2012).

Results and Discussion

The soil leaching methods used in this study represent a simplification of the natural processes. The metal movement with soluble organics in the field will be much slower than in the soil pots due to the heterogeneity of soils. The results of leaching with PLA in soil columns may represent a long period under natural field conditions. Soils amended either PL (Poultry litter) or PLA (Poultry litter ash) differed greatly from those with no litter application. PLA application to soils significantly increased average metals as compared to soils amended with PL or control. Unamended soil released the lowest amount of metals as compare to PLA and PL. For litter

Table 1
Selected Characteristics of Poultry litter and Poultry litter ash used for this study

Manure type	EC dSm^{-1}	pH (1:5)	TN	TC	Water Soluble			Ammonium acetate extractable			Total		
					K	Ca	Mg	K	Ca	Mg	K	Ca	Mg
			g kg^{-1}										
PL	13.1	7.7	55.5	408	26.1	3.1	1.4	0.85	1.70	0.10	42	18	7.9
PLA	31.1	11.5	18.5	231	48.9	0.5	0.4	2.31	4.63	0.16	154	100	20.3

	H_2O-Cu	H_20- Zn	H_2O Mn	H_20 Ni	Total Cu	Total Zn	Total Mn	Total Ni
	mgkg^{-1}							
PL	0.5	21.6	8.0	1.3	163.3	346.6	412.0	24.6
PLA	1.5	116.7	2.7	2.2	335.3	1080.0	1393.3	74.0

samples (PL and PLA) amended soils, manure types were differed in the order of PLA masa > PLA sand > PL masa > PL sand> Control. The pH of PLA was alkaline (11.5), with electrical conductivity of 31.1 mS cm^{-1}. (Table, 1) The EC values were slightly higher for PLA amendments than PL samples, and pH was higher for the PLA amendments as compare to control. Higher EC of the ash could be attributed to the conversion of organic compound into soluble inorganic compound. With this EC value, PLA could pose a salinity problem if applied in large quantities. For both materials, the pH was highly alkaline, especially in the burned samples, irrespective of the temperature levels.

Considerably greater concentration of P, K, Ca, Mg were noted from PLA amended masa and sandy soils as compared to PL amendments. Higher concentration in PLA amendment might be due to application of litter ash. In our previous experiments we characterized phosphorus and other nutrients and was found higher concentration of P and other nutrients in the poultry litter ash (Faridullah et al. 2008a and 2008b). The concentration of P, K, Ca and Mg in pre and post leaching soils considerably varied in order of PLA masa> PLA sand>PL masa >PL sand> Control.

For the two types of soils amended with PL and PLA Cu, Mn, Ni and Zn concentrations in the filtrates are presented in Figures 1- 5. Zinc concentrations in the PL amended with Masa, leachate concentration was 7.22 and PL sand was 7.45ml L^{-1} while 7.22 and 15.25ml L^{-1} was observed from PLA masa and PLA sand respectively. The lowest concentrations of Zn were obtained from control masa and sandy soils with 1.42 and 1.15mg L^{-1} (Figure 2). These results were probably due to preliminary sorption of organic ligands onto the soil with the creation of new sorbing surfaces. Mitchell et al. (1992) showed that Cu and Zn accumulated to toxic levels for plants in fields with a long history of broiler litter applications. Similar to poultry litter, long-term use of wastewater could elevate the trace element contents in soil (Page and Chang, 1985). In the PLA and PL amended soils, Zn was leached with H_2O due to solubilization by chelate formation**.** The concentration of trace elements in poultry litter and its by-products could be minimized by controlling the quality of raw feed materials and reducing mineral additives in poultry diet (Van Ryssen, 2008).

Mn and Zn leaching from different amendments varied in the order of PL masa> PLA masa > PL sand > PLA sand> Control masa> Control sand. Where as the concentration of Cu and Ni were observed as PLA masa > PL masa >PLA sand and PL sand (Figures 2-5). McBride et al. (1989) investigated a field site 15 years

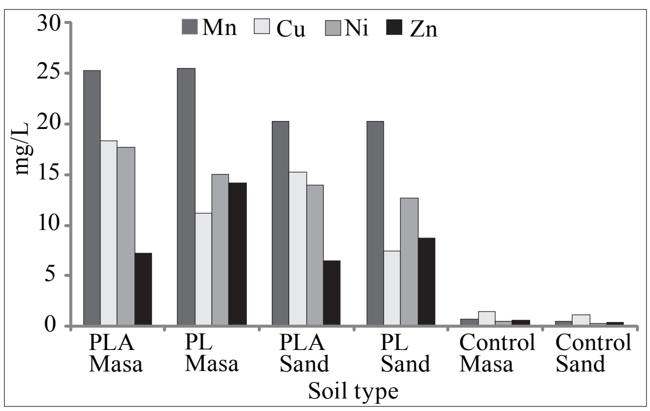

Fig. 1. Average concentration of Heavy metal in leachates

after a single heavy sewage sludge application. They found losses of the elements from the applied sewage. It can be inferred that amount of a particular nutrient does not depends upon the amount add to the soil but upon the source of nutrients applied.

The metals in the burned litter amended soils were very soluble. Even when deionized H_20 was used for leaching, the concentrations of metals in the leachate were higher, especially Zn, Cu, Mn and Ni at the beginning of the leaching period for PL and PLA. The leaching of Zn and Mn by the water extract was larger in PL amendments than that for the PLA (Figure 2) indicating a high potential to solubilize these metals in the soil. The water-soluble fraction is certainly the most biologically active. The high toxicity potential of this fraction is proven by the higher sensitivity exhibited by plants grown in hydroponic media. The water-soluble fraction has highest potential of contamination of food chain, surface water and groundwater. The patterns for leached Zn, Cu, Mn and Ni from the control were similar, while the leaching with PL and PLA amendment solutions was relatively higher at the initial three leaching (Figures 2-5). Despite the fact that leaching with PLA was less than that for PL in Zn and Mn, PL leached more Zn and Mn in the PL amended soil, suggesting the leaching ability of soluble organics.

In the masa and sandy, soils amended with PL, the total leaching of Ni in the leachate was 11.5 and 13.95 mg l^{-1} respectively, while the both soils amendment with PLA the Ni was 11.65 and 15.05 mg l^{-1}. In the Control soils, leaching of Zn was much lower than that with PL and PLA amendments. 1.42 and 1.15 mg l^{-1} was attained by control masa and sand dune soils respectively. (Table 2). The low leaching of Zn with PLA suggests that little Zn was present in the water-soluble forms in the Masa and Sandy soils. Because of

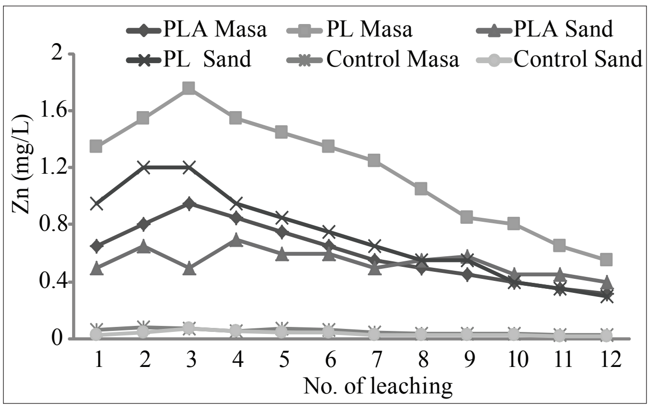

Fig. 2. Leaching fractions for Zn

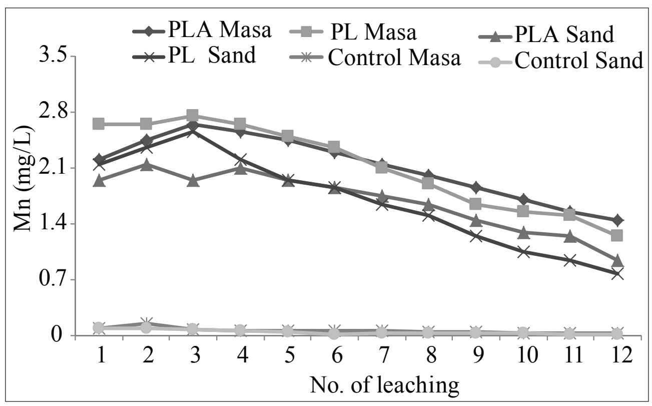

Fig. 4. Leaching fractions for Mn

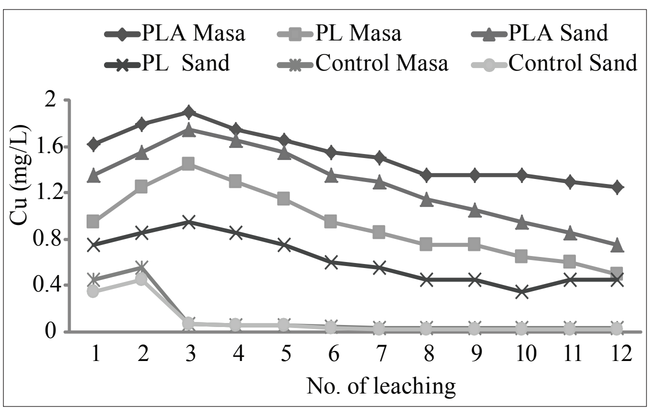

Fig. 3. Leaching fractions for Cu

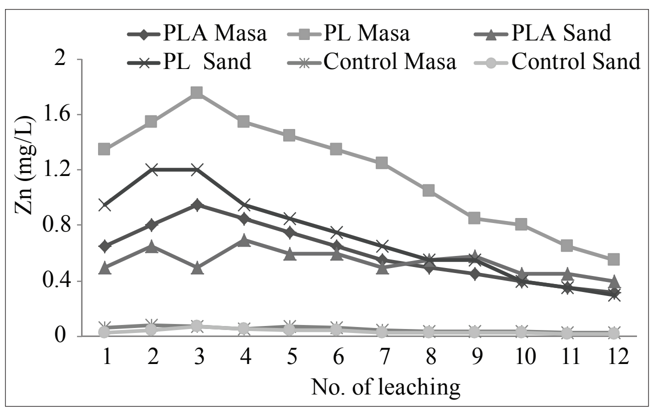

Fig. 5. Leaching fractions for Ni

Table 2
Average concentrations of Mn, Cu, Ni and Zn (mg kg^{-1}) in leachates

Soil type	Manure type	Cu	Mn	Ni	Zn
Masa	PLA	18.33	25.37	17.66	13.88
	PL	11.14	25.43	15.06	14.16
	Control	1.41	0.78	0.49	0.62
Sand dune	PLA	7.46	20.22	12.66	8.73
	PL	15.26	20.23	13.94	6.47
	Control	1.16	0.63	0.28	0.43
	LSD (0.05)	0.38	0.17	0.03	2.41

the coarse soil texture, most of soluble Zn in this soil may be leached by irrigation over different fractions. Under these circumstances, a large amount of soluble organics could solubilize Zn from the soil. Boyle and Fuller (1987) found that high organic carbon in the irrigation solution facilitated the migration of Zn through a soil. This is consistent with the results in the present study. The dissolved organic matter in the PLA was effective in solubilizing Zn in this soil. This suggests that the application of poultry litter on soils with high metal content would increase the movement of Zn in the soil profile. In the soil, the pattern of Zn leaching with solution (Figures 2-5) was similar to that for Cu and Mn. The leaching of Zn with PLA and PL in the sand dune soil was smaller than that for the masa-amended soils because of the lower total Zn concentration in the PL than in the PLA amended soils (Table 1)

Soluble organic substances in the poultry litter can be effective ligands to form soluble metal-organic complexes (McBride, 1989) and, thus, increase metal mobility in the soil profile. However, with a large amount of sorption sites, solid organic matter might increase metal adsorption on soil solid phases. Therefore, field application of poultry litter may alter metal physicochemical forms, change metal distribution in soil fractions and possibly influence metal mobility. The amounts of water-soluble Cu and Mn varied with soil type and increased with increasing total Cu or Mn concentrations in PLA and PL amendments. Mn concentrations in the PL Masa leachate were 25.50 and PL sand was 20.22mg liter^{-1}, where as 25.30 and 20.30 mg litter^{-1} was observed from PLA masa and PLA sand respectively. The lowest concentrations of Mn were obtained from control masa and sandy soils with 0.74 and 0.54mg L^{-1} (Figure 4). For the sake of shortening the duration of breeding, a great deal of additives Cu and Zn are widely applied to livestock and poultry feed, which result in high concentrations of Cu and Zn in manures (Cang et al., 2004). Usually, these poultry and livestock manures are used as soil amendment to enhance the soil fertility (), but Cu and Zn contained in the manures may accumulate in the soil to toxic levels after long-term application (Mitchell et al., 1992). The mobility of heavy metals in terms of their leach ability depends not only on their total concentrations in the soil but also on the soil physicochemical properties and environmental factors (Li and Shuman, 1997). Boyle and Fuller (1987) found that Zn leaching through soil columns was enhanced by elevating the dissolved soil organic carbon (DOC). Undoubtedly, livestock and poultry manures contain high contents of organic material, which can contribute organic ligands to form metal complexes in soil (McBride, 1989). Such complexes can be transported with water movement and possibly into groundwater. Shuman (1990) reported that 0.01 mol L^{-1} $CaCl_2$ solution has comparable ionic strength chemical fertilizers are applied to the soil. Raining or irrigation will result in eluviation of ions in the soil. Three common practices are adopted for litter management in broiler units (Bernhart et al., 2010). These include single use litter, partial re-use and multi-use litter. The amount of feed spilt during feeding can significantly affect the total amount of solid and nutrients remaining in the litter (Leytem et al., 2007).

Because of the intensity of production, a number of feed ingredients, including trace elements such as As, Co, Cu, Fe, I, Mn, Se, and Zn, are used in poultry industry to prevent deficiencies and diseases, improve weight gains and feed conversion, and increase egg production in the case of poultry (Powers and Angel, 2008; Burel and Valat, 2009).

Metal mobility in soil is closely related to the physicochemical forms in the solid phases. Metals in different chemical forms have different labilities, bioavailability and susceptibility to leaching. Selective sequential extraction is a technique used to determine the solid phase forms of metals in soil, and the fractions in soil are thus operationally defined. Many sequential extraction procedures have been developed for determination of metal in soils and manure fractions. Different methods are useful for different sources of soils or suitable for different soil conditions and amendments. The water-soluble and exchangeable forms characterize the most mobile and immediately bioavailable forms. They are the most labile metal forms in the soil environment and have greater leaching potential than the other forms (Faridullah et al., 2008a; 2008b). With this technique, it is possible to determine the quantity and sources of the metals being solubilized from soil solid phases. Dissolved organic matter in poultry litter could contribute effective organic ligands to form complexes with heavy metals in soil (McBride, 1989; Bolton & Evans, 1991). As compared with other studies (Jones and Turki, 1997), the sandy soils in this study had lower proportions of residual Zn and Cu fractions. Higher proportions of non-detrital metals, including exchangeable, carbonate-bound, organically bound and oxide-bound fractions, in the soils suggested that the soils had considerable potential for Cu and Zn loss to the environment. (Faridullah et al., 2008)

Cu and Zn are strongly bound to organic matter and the land application of organic matter-rich poultry manure is likely to result in the accumulation of such metals in soils (HE et al., 2009). Over-supplementation of Cu and Zn do not seem to have direct environmental effects but are potentially phytotoxic (Novak et al.,

Fig. 6

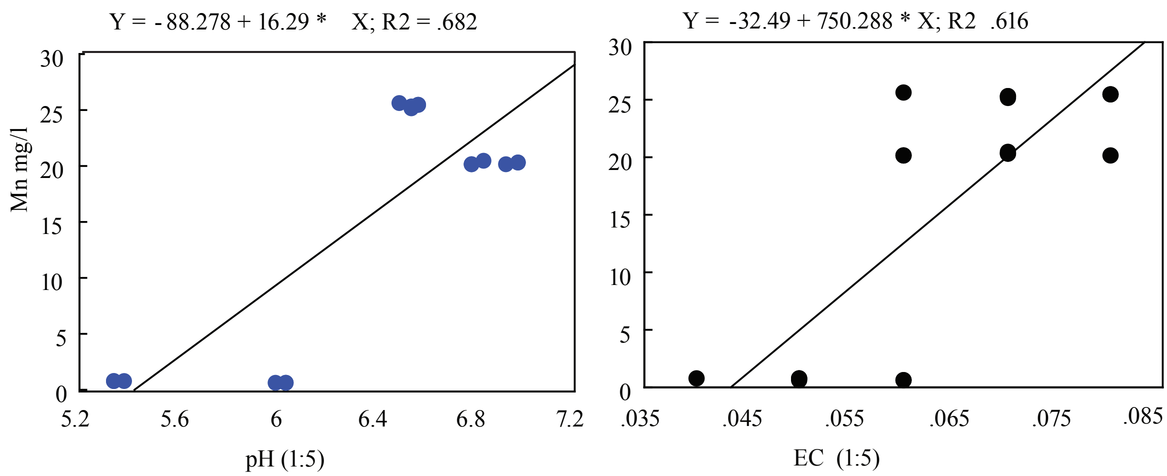

Fig. 7

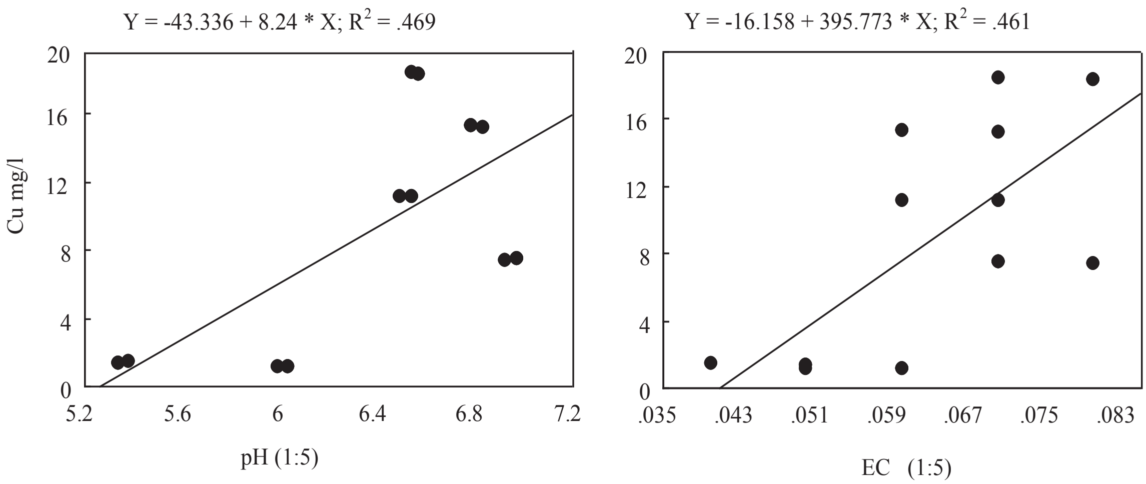

Fig. 6 and 7. Release of Cu and Mn, concentration from two types of soil amended with poultry litter and poultry litter ash with a wide range of pH and EC

2008). The environmental risk of heavy metals such as Cu and Zn is largely dependent upon the ability of the soil to adsorb these elements and the potential for leaching or loss by soil erosion (Gupta and Charles, 1999).

A linear correlation was obtained between the total leaching amounts of Zn, Cu, Ni and Mn with pH and EC in each soil column (Figures 6-9).

The differences in water-soluble Cu or Zn between the soils and manure types were probably due to the differences in soil pH and Ca ($CaCO_3$) content, as pH were higher in the litter ash than in the unburned material (Table 1). Greater sorption affinity and/or precipitation in soils with a higher pH have been reported. Nonetheless, low critical values for all metals in the both soils suggested that accumulation of above metal in the soils posed a great risk of metal toxicity in water. Metal concentrations in leachates varied with soils and manure types and with their respective total Cu,Zn, Mn and Ni concentrations. The slope of the linear relation between the Cu, Zn, Mn and Ni concentration and soil pH was very small. Additionally, Yong and Phadungchewit (1993) reported that a change in soil solution pH resulted in a corresponding change of the dominant retention mechanisms of metals in soils. The pH effects were also thought to relate to the exchange

Fig. 8

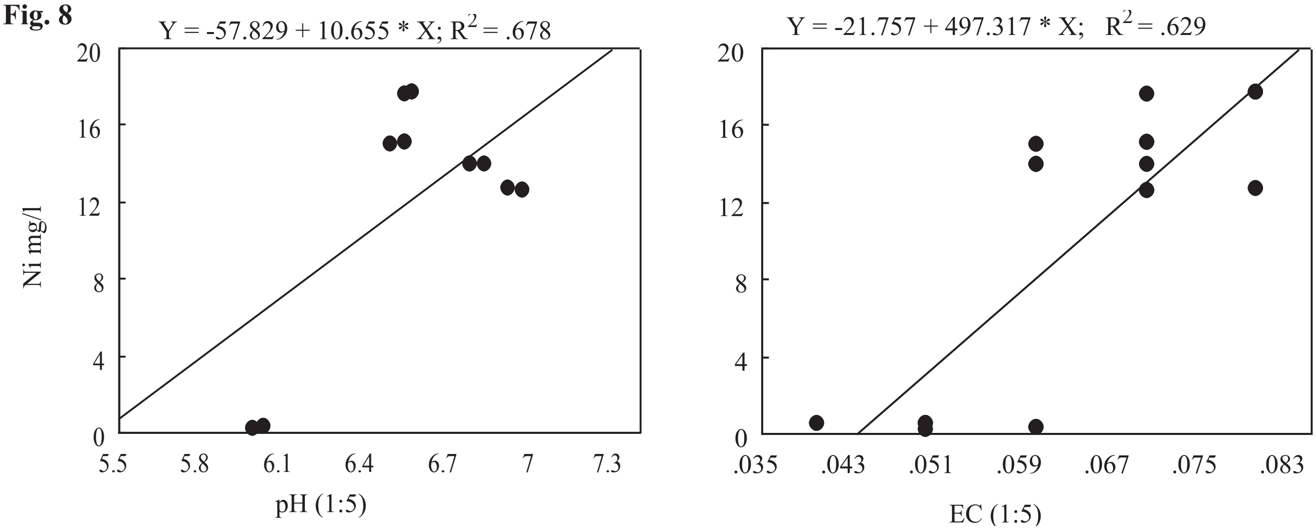

Fig. 9

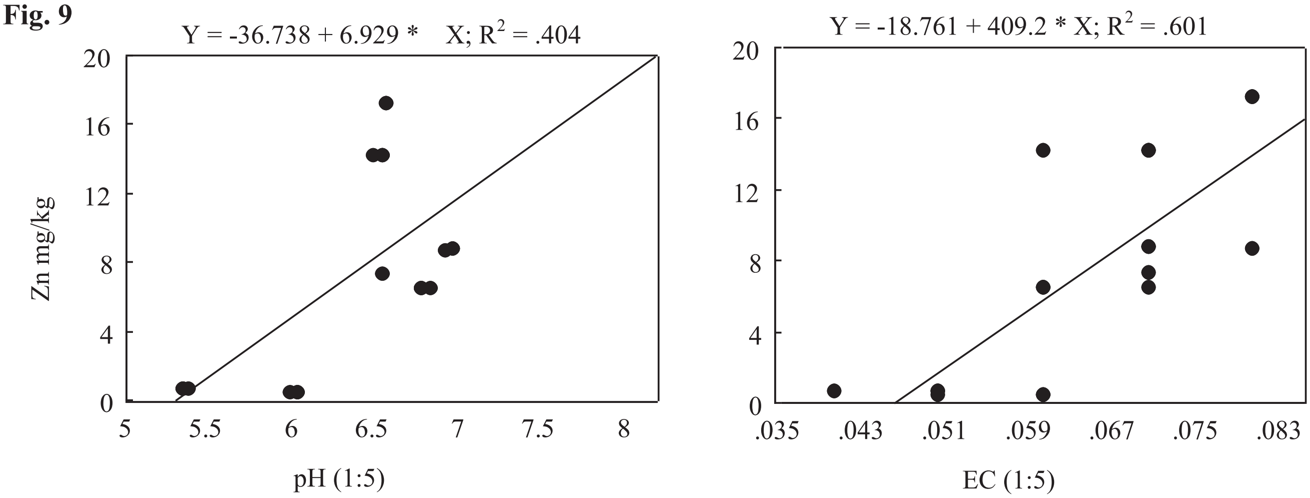

Fig. 8 and 9. Release of Zn and Ni, concentration from two types of soil amended with poultry litter and poultry litter ash with a wide range of pH and EC

of H^+ with metals and the effect of pH on dissolution-precipitation and oxidation of Fe and Mn oxides

Conclusions

Poultry litter, a combination of excreta, feathers, wasted feed, and bedding materials, is a valuable by-product of poultry production. It has been used as a soil amendment for decades to enhance soil fertility .Although poultry litter rarely contains high contents of potentially harmful metals.

The sandy soils had a low affinity and sorption capacity for heavy metals; they were sensitive to runoff loss of metals. Higher proportions of non-detrital metals, including exchangeable, carbonate-bound, organically bound and oxide-bound fractions, in the soils suggested that the soils had a considerable potential for Cu, Mn, Ni and Zn loss to the environment. With an increasing accumulation of these metals, the potential for their loss to surface waters also increased. The extractability of these metals increased with increasing soil Cu, Mn, Ni, and Zn accumulation. There were obvious critical concentration levels of the metals in the soils, above which the solubility of these increased rapidly. The soluble metals in the soils mainly originated from the exchangeable fractions. The highest concentrations of Zn, Mn, Ni and Cu were found in the leachate of the PL column and the total amounts of Cu, Mn, Ni and Zn eluted from the two soils amended with PLA and PL. The concentration of these metals varied considerably in the order of PLA masa > PLA sand > PL masa > PL sand > control. If the soil receiving intensive manures is heavily irrigated or it receives precipitation, the elution of soil heavy metals would pose a threat to groundwater.

From our studies of the leachate collected from litter ash-amended soil columns, we conclude that all significant trace metals existed mostly as organic complexes in the soil solution. Thus, metal displacement in the soil is favored through the association with mobile organic molecules from the burned and unburned poultry litter. However, in all soils studied, the large majority of water-extractable trace metals applied with the PL and PLA are not expected to leach in the short term. For sandy soils, trace metal mobility is higher and trace metals show a potential for rapid vertical displacement.

The soluble complexes with heavy metals can be transported downward and possibly deteriorate groundwater quality. Not only poultry litter, but also sewage sludge and forest litter can release a large amount of soluble organic ligands. The addition of soluble organic ligands has been found to decrease the sorption of trace metals by soils. Environmental hazards derived from heavy metals are closely linked to metal mobility, and thus to the concentrations of the metals in the soil solution. The mobility of heavy metals in terms of leach ability depends not only on the total concentration in soil but also on soil properties and environmental factors. The movement of heavy metals in soil profiles has received considerable attention, since even a slow transport through soil and subsoil materials may result in an increased content of heavy metals in the groundwater.

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Received December, 10, 2011; accepted for printing June, 2, 2012.