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Trace Metal Enrichment and Distribution in a Poultry Litter-amended Soil under different Tillage Practices

Ngowari Jaja[1,*], Monday Mbila[2], Eton E. Codling[3], Seshadri S. Reddy[4] and Chandra K. Reddy[5]

[1]*Agriculture Research Station, Virginia State University, Petersburg, VA, USA*

[2]*Department of Biological and Environmental Sciences, AAMU, Normal AL, USA*

[3]*USDA-ARS Environmental Management and Byproduct Utilization Laboratory, Beltsville, MD, USA*

[4]*Agricultural Research Center, Kansas State University, Hays, KS, USA*

[5]*College of Agriculture, Human and Natural Sciences, Tennessee State University, Nashville, TN, USA*

Abstract: Macro and micro nutrients enrichment from poultry litter amendment, tillage, and crop rotation have been investigated to determine their impacts on crop yield, soil and environmental sustainability. This study was conducted to evaluate the soil arsenic (As), copper (Cu), lead (Pb), nickel (Ni) and zinc (Zn) enrichment that could result from the long term effect of poultry litter amendments and tillage practices on selected soil properties at the Alabama Agricultural Experiment Station, Belle Mina, AL. Soil samples were collected in 2006 from plots established in 1996 that received yearly poultry litter applications with three tillage systems, conventional-till (CT), no-till (NT), and mulch-till (MT); and at three depths (0-10 cm, 10-20 cm, and 20-30 cm) that received poultry litter based on 100 kg total N ha^{-1} yearly. An untreated control was also included in the study. Soil pH values at the 0-10 cm were greater or equal to the lower depths. Copper and Zn concentrations were significantly higher for all tillage systems at the 0-10 cm depth compared to the 10-20 and 20-30 cm depths and decreased with increasing depth. For example, at 0-10 cm depth Cu concentrations were 58, 66 and 65 and Zn were 13, 24 and 22 percent higher than the control for the CT, MT and NT tillage practices respectively. These results demonstrated that Cu and Zn did accumulate in the surface soil after 10 annual applications of poultry litter but not at phytotoxic levels in contrast to As, Pb, and Ni regardless of the tillage practices.

Keywords: Agronomic Practices, Poultry Litter, Trace Metals, Tillage Systems.

INTRODUCTION

Agronomic practices such as poultry litter amendment of soils, tillage regimes, and crop rotation patterns have been investigated to determine their impacts on yield and sustainability in agricultural ecosystems. Such agricultural practices have also been implicated in trace metal contamination of the environment [1-3]. In a study to evaluate the effect of conventional and zero tillage systems on the distribution of heavy metals in wheat, corn, and soybean grown on a Typic Argiudoll soil, tillage treatments influenced plant accumulation of heavy metals in different plant tissue systems [4, 5]. Fertilizer application and other soil amendments such as biosolids and poultry litter have also been shown to contribute to the release of heavy metals in the soil, particularly in areas where poultry and other animals are produced in large quantities [6, 7]. Additionally, increased use of trace elements as nutritional supplements in poultry diets to improve feed efficiency, facilitate weight increase, and for disease prevention resulted in high levels of trace elements in poultry litter [8, 9]. In intensive animal production industries, land application of manure has emerged as an important source of certain metals (e.g., As, Cu, and Zn) input in soils. Unlike application of sewage sludge, where application rate is limited based on allowable metal loadings by EPA 503 regulations [10], regulations governing livestock and poultry manure by-products are generally based on total N and/or P loading [11]. The danger lies in accumulation of manure-borne metals, since they are not biodegradable and eventually become phytotoxic [11]. Long-term application of poultry litter has also been shown to result in accumulation of trace elements, increasing the potential bioavailability and toxicity of the metals in the environment [2, 9, 12, 13]. Such accumulation has the potential of restricting soil functions, contaminating the food chain, and causing toxicity to plants, animals and humans [14, 15].

In urban or agroecosystems with a long history of urbanization and crop production, the concentrations of trace elements in soil can be higher than those found in the parent materials. Elevated concentrations of trace elements in disturbed environments may be due to the application of the elements Cu, Zn, Fe, Mn, and B to plants for correcting nutrient deficiencies [16] or addition of Cd and Pb as impurities in fertilizers. Other agricultural chemicals that result in the loading of trace metals in soils include fungicides, pesticides,

*Address correspondence to this author at the Agriculture Research Station, Virginia State University, Petersburg, VA, USA; Tel: 804-524-5379; Fax: 804-524-5622; E-mail: ngo.jaja@gmail.com

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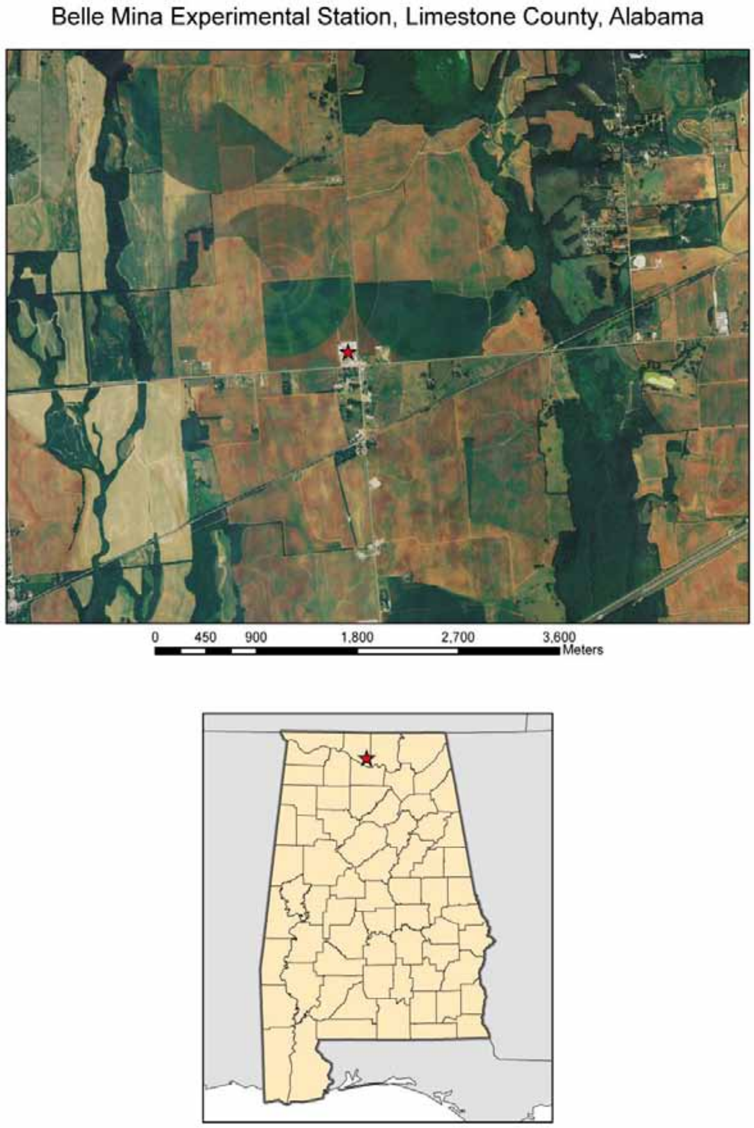

Fig. (1). Location Map of the Sampling Site.

algaecides, parasiticides, herbicides, biosolids, and other amendments. Trace metals from these sources also end up in the soil where their redistribution is dependent on the biogeochemical cycles that impact plant and animal lives [14].

Tillage techniques affect the soil's physical, chemical, and biological properties that influence root biomass distribution in the plow layer [17-19]. This effect in turn gives rise to changes in bioavailability of trace elements in the root zone. Also, when soils are not plowed for a long time, as in no-till farming, soil organic matter and other nutrients tend to stratify [4]. This stratification increases the nutrient availability and root absorption of trace elements, which could have a significant impact on the environment.

In a long-term study established in 1996 at the Tennessee Valley Research and Extension Center in Belle Mina, Alabama, the effect of poultry litter application as a nutrient source for cotton based cropping systems was studied under different tillage regimes. It is well known that tillage methods and organic amendments influence the physical and chemical properties of the soil [13, 17-19]. Since agronomic practices such as tillage practices and application of fertilizer and manure contribute significantly to trace metal accumulation and redistribution in soil and water resources, it is relevant to investigate these relationships. Therefore, the objective of this study was to evaluate trace metal enrichment and distribution in soil resulting from the long term application of poultry litter amendment coupled with three tillage regimes.

MATERIALS AND METHODS

Site Description and Field Experiment

A long-term field study was initiated in 1996 at the Tennessee Valley Research and Extension Center in Belle Mina, Alabama (formerly, Alabama Agricultural Experiment Station, Belle Mina) (34^o 41' N, 86^o 52'W) (Fig. **1**) on a Decatur silt loam (clayey, kaolinitic thermic, Typic Paleudults) soil. The objective of the study was to determine the impacts of poultry litter use, tillage practices, and crop rotation patterns on yield and sustainability of selected crops. The experiment was composed of three tillage methods (conventional-till, no-till, mulch-till), two cropping systems (cotton in summer-fallow in winter; cotton in summer-rye in winter) and two sources of nitrogen: poultry litter and ammonium nitrate. In total, there were twelve treatments laid out in a randomized complete block design with plot size of 8 m by 9 m having eight rows of crops [20]. There were three replicates from three blocks. Out of the twelve treatments, four were selected for this study in 2006. Three of these treatments had identical concentrations of poultry litter as the nitrogen source and different methods of tillage, while the fourth was a fallow control with no applied nitrogen or tillage (Table **2**). The first method of tillage consisted of conventional-tillage (CT) in which plots were prepared for planting with multiple operations of implements such as moldboard plow, disk, and spring-tooth harrow, which completely inverted and exposed the soil to the weather. This tillage left less than 15% crop residue cover. The second method was no-till (NT), where the soil surface was not disturbed; crops were planted by drilling directly into the seedbed. Most of the crop residue was retained on the surface. The third method was mulch tillage (MT), also called conservation tillage, which retains 30 % of crop residues on the surface of the soil. The poultry litter as a nitrogen source was applied in early spring by manually broadcasting the litter on all plots.

Soil Sampling and Preparation

Soil samples for chemical analyses were taken in the late spring of 2006 from three depth increments (0-10 cm, 10-20 cm, and 20-30 cm). Two composite samples were taken from each plot. Soil samples were also collected from the control for the purpose of comparison with the treated plots. Soil and poultry litter samples were air-dried, crushed with porcelain mortar and pestle, and passed through a 2-mm sieve according to standard procedures, and then stored for analysis.

Laboratory Analyses

Poultry litter and soil samples were analyzed for total trace metals according to [21] modified with the EPA Method #3052 (Microwave Accelerated Reaction System (MARS) for complete digestion. For quality control, blanks were run along with the poultry litter and soil. After digestion, samples were cooled and filtered through #42 Ashless Whatmann Filter paper and stored for analysis. Trace metal concentrations of the extracts were determined with a Perkin Elmer 2100 ICP-OES following standard operating procedures required for the instrument.

Statistical Analyses

All statistical analyses were performed with the general linear model (GLM) procedure of the Statistical Analysis System (SAS) version 9.3 [22]. Duncan Multiple Range Test was used for separation of means at $p < 0.05$ [23].

RESULTS AND DISCUSSION

Trace Metal Content of Poultry Litter and Control Soil

The levels of arsenic (As), copper (Cu) and zinc (Zn) concentrations in the Belle Mina, Alabama, poultry litter samples were higher than the control soil, while lead (Pb), and nickel (Ni) were higher in the soils (Table **1**). Copper, zinc, and arsenic are commonly added to poultry feed in trace amounts as part of a diet designed to optimize bird growth and performance [24]. The concentrations of Cu (735 $\mu g\ g^{-1}$) and Zn (428 $\mu g\ g^{-1}$) were within the normal ranges for these elements in poultry litter in the Southeastern United States [25], but slightly higher than the averaged (390 and 377mg kg-1 for Cu and Zn respectively) reported by [26]. Ritz *et al.*, (2005) [27] and Kunle *et al.*, (1981) [26] reported wide variations in poultry litter nutrient contents; they concluded that storage and handling or management resulted in the nutrient variation. Since this characterization is not available for this poultry litter, future research is needed to periodically sample and characterize it in order to monitor variations in trace metal behavior over time.

TRACE METAL ENRICHMENT AND DISTRIBUTION IN POULTRY LITTER AMENDED SOIL UNDER DIFFERENT TILLAGE SYSTEMS

Soil Description

Soil sampled from the 0-10 cm depth was a dark reddish brown (5YR 3/2) silt loam with moderate fine granular structure and moderate acidity, whereas at the 10-30 cm depth the soil was a dark reddish brown (2.5YR 3/4) silty clay loam with moderate and medium sub angular blocky structure and evidence of clay accumulation. The soil was very deep, well drained, moderately permeable, and was formed in residuum derived from limestone. The soil's characteristics are consistent with the Decatur Silt Loam Series (Fine, kaolinitic, thermic Rhodic Paleudults).

Soil pH

Soil pH ranged from 5.4 to 6.2. At the two shallower depths, soil pH was higher in the three poultry litter treatments compared to the control (Fig. **2**). At the 20-30 cm depth, however, soil pH was significantly higher than in the control only in the no-till (NT) treatment. Comparing tillage practices, soil pH at the 0-10 cm depth was highest in the NT treatment, while at the 10-20 cm depth the mulch till (MT) treatment had highest pH. The relatively high pH of the shallowest depth of the NT treatment may have resulted from the broadcast application of poultry litter, which has been reported to have a pH ranging from 6.5 to 7.5 [28].

Enrichment and Distribution of Zinc

At all soil depths, there was a trend of increased soil Zn concentration with poultry litter application, compared to the control, although the increases were not always significant (Fig. **3**). Comparing tillage regimes, at the 0-10 cm depth, Zn concentration was higher in the NT and MT treatments compared to the conventional till (CT) treatment, although the difference was significant only for the MT treatment. Zn concentration was lower at the lower soil depths. The relatively high Zn concentration in the 0-10 cm depth, especially in the two reduced tillage treatments, shows evidence of Zn accumulation due to minimum disturbance of the soil. At the 20-30 cm depth, on the other hand, the effect of tillage on Zn concentration trended the other way, indicating increased mobility of Zn resulting from soil disturbance in the CT treatment.

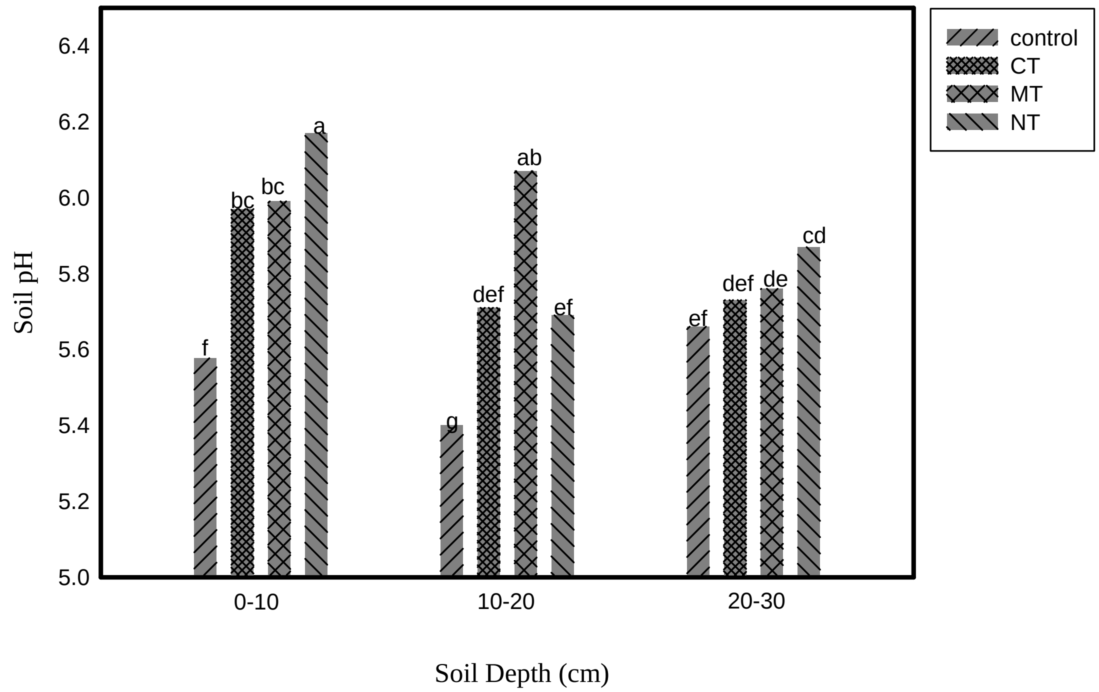

Fig. (2). Soil pH as affected by poultry litter, conventional tillage (CT), mulch tillage (MT) and no-tillage (NT) practices at different depths. Columns having letters in common are not significantly different at $p<0.05$ level.

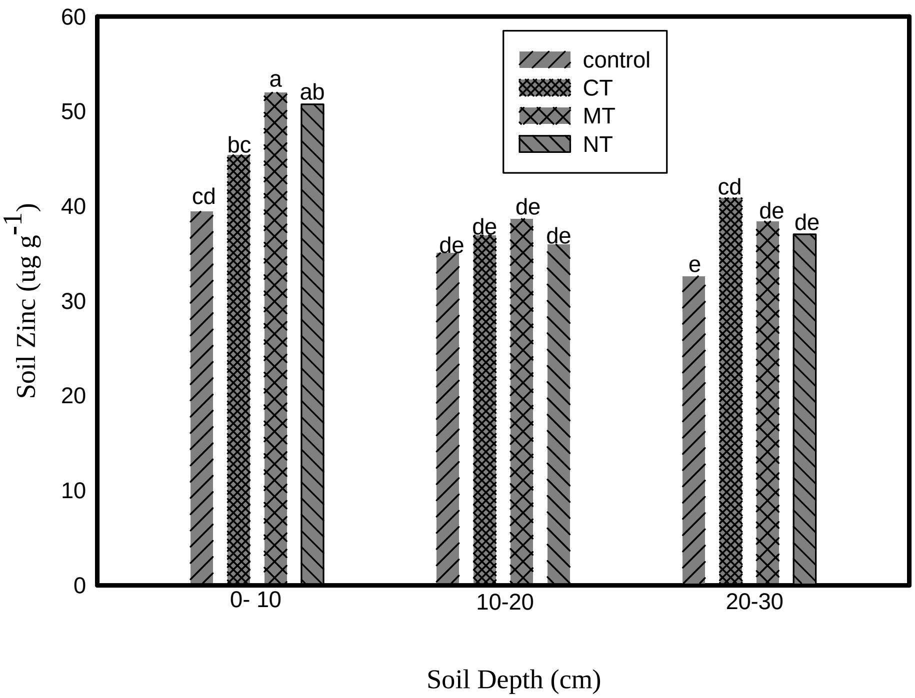

Fig. (3). Soil zinc as affected by poultry litter, conventional tillage (CT), mulch tillage (MT) and no-tillage (NT) practices at different depths. Columns having letters in common are not significantly different at $p<0.05$ level.

The observed soil Zn distribution reflects the Zn content of the added poultry litter. Zn is one of the elements added to poultry feed. Research findings on the increase of soil metals resulting from poultry litter application is mixed, for example, [11] reported increase in soil Zn concentration with poultry litter application. Gupta and Charles (1999)[29], however, observed no significant difference in Zn concentration as a result of poultry litter application in corn production compared to the control soil. Schomberg *et al.*, (2009)[5] also observed lower Mehlich-1 extractable Zn in surface soil amended with poultry litter during 5 years of cotton production compared to un-amended soil.

Enrichment and Distribution of Copper

Similar to the results for Zn, there was a trend of increased soil Cu concentration in poultry litter amended soil

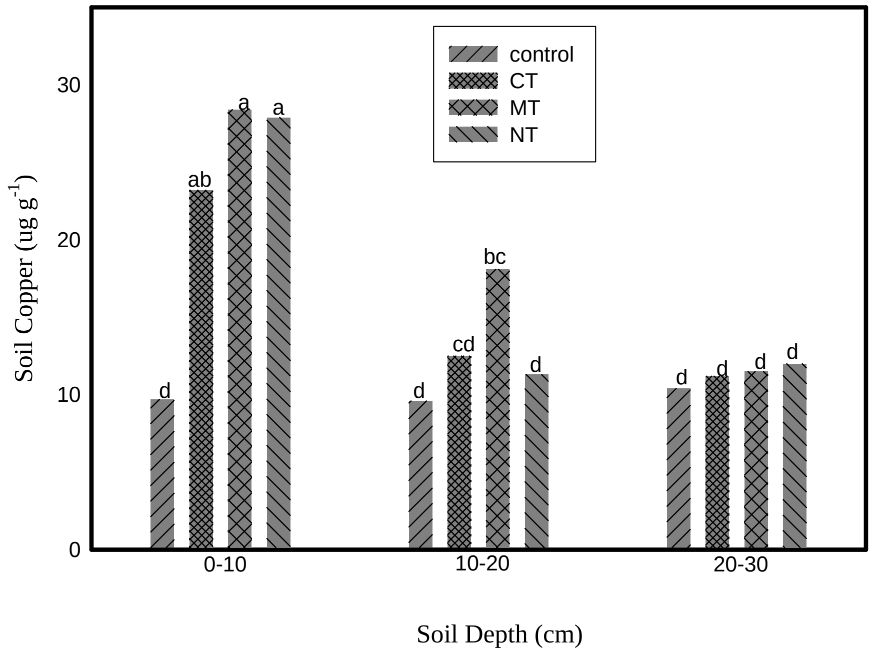

Fig. (4). Soil copper as affected by poultry litter, conventional tillage (CT), mulch tillage (MT) and no-tillage (NT) practices at different depths. Columns having letters in common are not significantly different at p<0.05 level.

Table 1. Total Arsenic (As), Copper (Cu), Lead (Pb), Nickel (Ni) and Zinc (Zn) Concentration in Control Soil and Poultry Litter

As	Cu	Pb	Ni	Zn
------------------$\mu g\ g^{-1}$------------------				
Control Soil				
18.3	9.90	22.4	10.1	35.7
Poultry Litter				
38.0	735	9.2	8.20	428

across tillage practices, compared to the control treatment, with the highest concentrations in the 0-10 cm depth (Fig. **4**). With exception of the 10-20 cm depth of the MT treatment, at the two lower soil depths there were no significant differences in Cu concentration attributable to poultry litter application or tillage practice. As was seen for Zn, the distribution of Cu in the soil can be explained by the Cu content of the applied poultry litter (Table1). Kunle *et al.* (1981)[26] observed a linear relationship between Cu added in the poultry diet and that found in poultry litter. They concluded that Cu concentrations in the poultry litter were 3.25 times higher in the litter than the feed. Bolan *et al.*, (2004)[11] also reported that the metal content of poultry litter depends primarily on the amount used in the feed. Copper concentration was 72 percent higher than Zn in the poultry litter (PL) used in this study (Table **1**); however, Cu concentration was much lower than Zn in the soil extractable solution (Figs. **3** and **4**). For example, at the 0-10 cm depth Zn concentrations were 45, 52 and 51 $\mu g\ g^{-1}$ compared to 23, 28 and 28μg^{-1} for Cu for the CT, MT and NT treatments respectively.

Enrichment and Distribution of Lead, Arsenic and Nickel

Lead (Pb) concentration in the soil samples ranged from 19 to 24$\mu g\ g^{-1}$. Lead concentration among the different tillage systems was not significantly different and does not give any indication of accumulation nor mobility between the depths (Fig. **5**). Lead concentration did not change significantly due to PL applications compared to the control. It could be due to very low concentration of Pb in the PL compared to the natural concentration in the soil (Table **1**). The observed soil Pb concentrations were within the range considered normal in surface soil (10–150 $\mu g\ g^{-1}$) [30].

Arsenic concentration in the soil ranged from 15 ug g^{-1} to 21 ug g^{-1} and does not significantly differ among depths or tillage practices (Fig. **6**). This is also reflective of the As concentration in the PL shown in Table **2** which indicated that the As content is much lower than the level for Cu and Zn even though, As have been added to poultry diet [24].

There was also no indication of any accumulation since the As concentrations in the control were similar to the others treatments.

Nickel concentration in the soil ranges from 10 to 11 $\mu g\ g^{-1}$ for all the tillage plots (Fig. **7**). The application of the poultry litter did not show any significant change in the concentration of Ni in any of the tillage plots when compared with control plot. This also appears to be a direct relationship with the concentration of Ni in the PL as shown in Table **1**. This agrees with most work done on PL since Ni has not

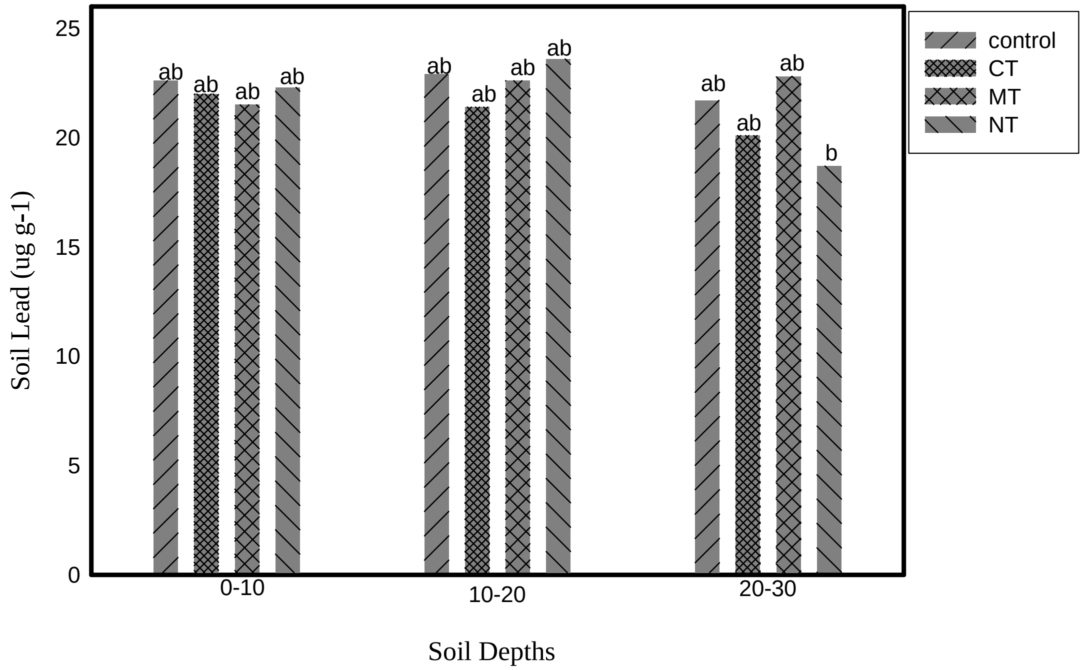

Fig. (5). Soil lead as affected by poultry litter, conventional tillage (CT), mulch tillage (MT) and no-tillage (NT) practices at different depths. Columns having letters in common are not significantly different at p<0.05 level.

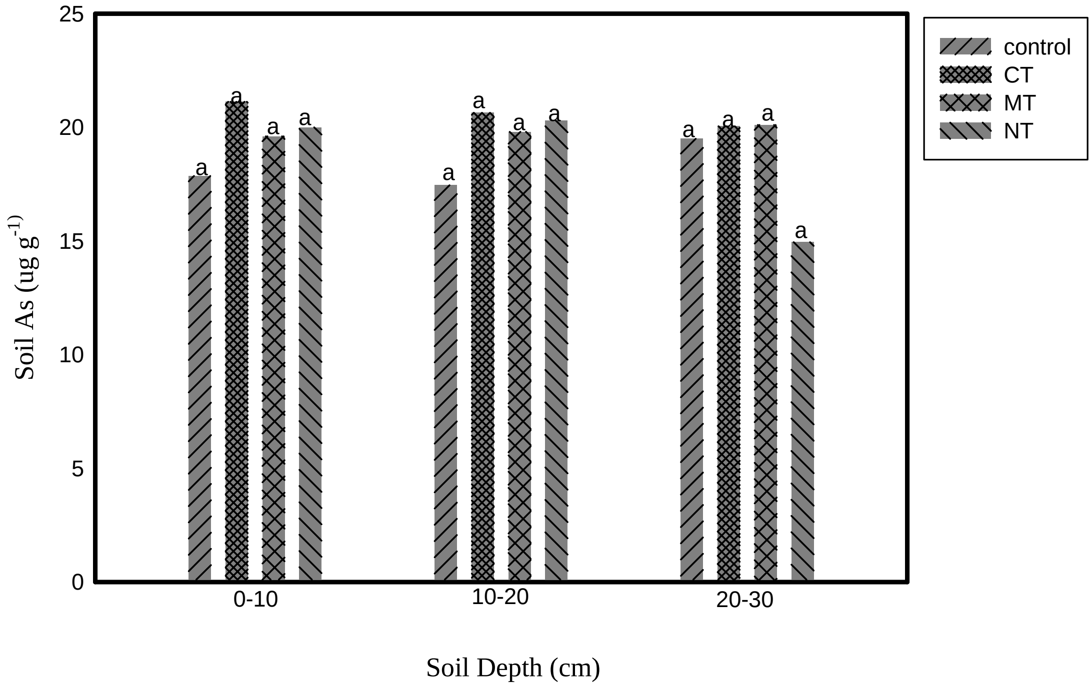

Fig. (6). Soil Arsenic as affected by poultry litter, conventional tillage (CT), mulch tillage (MT) and no-tillage (NT) practices at different depths. Columns having letters in common are not significantly different at p<0.05 level.

Table 2. Poultry Litter Application at the Research Site in Belle Mina, AL

Treatment	Tillage	Cropping System		Nitrogen Source	Nitrogen Rate Kg ha^{-1}
		Summer	Winter		
1	Conventional-till	Cotton	Rye	Poultry Litter	100
2	Mulch-till	Cotton	Rye	Poultry Litter	100

Table 2. contd…

Treatment	Tillage	Cropping System		Nitrogen Source	Nitrogen Rate Kg ha^{-1}
		Summer	Winter		
3	No-till	Cotton	Rye	Poultry Litter	100
4 (Control)	None	Fallow	Fallow	None	0

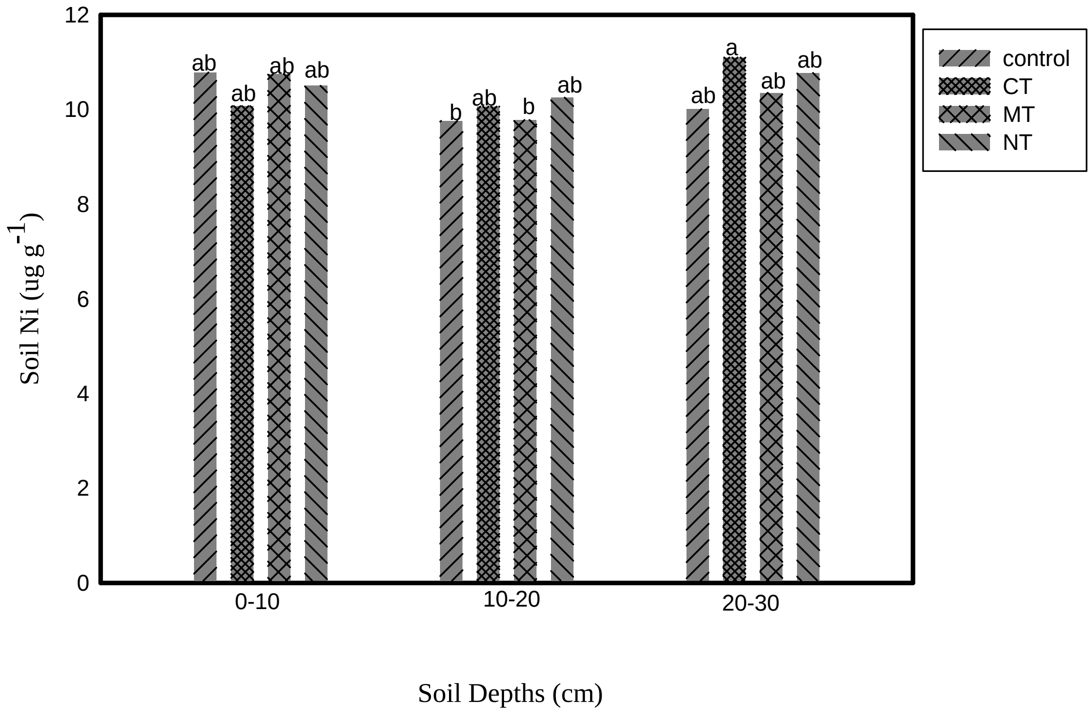

Fig. (7). Soil Nickel as affected by poultry litter, conventional tillage (CT), mulch tillage (MT) and no-tillage (NT) practices at different depths. Columns having letters in common are not significantly different at p<0.05 level.

been implicated as one of the environmental concerns of poultry litter application in an agroecosystem. Soil Ni concentrations [31] at the soil surface, were also within the range considered normal (2–100 µg g^{-1}), [30].

CONCLUSION

With the exception of Cu and Zn, poultry litter application and tillage practices did not significantly influenced soil metal concentration after 10 annual applications of poultry litter.

Most of the Cu and Zn remained in the 0-10 cm depth. Averaged over the tillage at the 0-10 cm depth metal concentrations were as follow Zn > Cu > Pb >As >Ni. The mulch and no-tillage treatments have the highest Zn and Cu concentration compared to conventional till. In this study, As, Cu, Zn, Pb and Ni concentrations were within levels generally found in Agricultural soils. Therefore, the metal concentrations found in this poultry litter amended soil should not be phototoxic or harmful to the environment.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

ACKNOWLEDGEMENTS

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