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Trends in Trace Elements in an Ultisol Impacted by Long-Term Applied Broiler Litter

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In the United States, the poultry industry generates over 50% of the agricultural profits while utilizing nearly 80% of the grain produced for feeds (Nyakatawa et al. 2001). The litter generated from broiler operations is primarily composed of bird droppings, bedding materials, feathers, drug residues, and unconsumed feeds (Kpomblekou-A et al. 2002). An estimated 1 kg of litter is generated for each kg of broiler produced (Van der watt et al. 1994). In 1996, over 11.4 million Mg of broiler litter was generated of which over 90% was land-applied (Cabrera and Sims 2000). Based on the 1999 report obtained from the Alabama Agricultural Statistics Service, the State of Alabama accounted for over 971 million birds and generated approximately 1.5 million Mg of broiler litter that was mainly used for pasture growth (Kpomblekou-A et al. 2002).

Various concentrations of metals (As, Co, Cu, Fe, Mn, Se, and Zn) depending on their sources are added to poultry diets to enhance weight increase and disease prevention (Sims and Wolf 1994; Han et al. 2000; Jackson et al. 2003). The addition of copper sulfate (125 or 250 mg kg^{-1}) to broiler chicken diets enhances weight gain and feed efficiency (Miller et al. 1986), while Fe and Zn are supplemented to balance the ration. In 2002, Kpomblekou-A and others analyzed broiler litters from broiler operations in 12 counties in Alabama and found the litter to contain on the average total organic carbon ranging from 229-396 g kg^{-1}, C/N 6.86-11.4, moisture 7.9-28.5%, as well as higher levels of Ca, Mg, K, Na, Fe, Cu, Zn and Al.

Broiler litter has been a source of nutrients for corn, small grains, fruits, forage grasses, and vegetables productions (Bitzer and Sims 1988; Wood et al. 1993; Evers 1998). It is a relatively inexpensive source of N, P, K, Ca, Mg, S, Cu, Fe, Mn, and B. Broiler litter applied to agricultural lands does enhance soil productivity and quality by improving aggregate formation and stability. But, repeated land applications may result in detrimental buildup of elements beyond the required concentrations for plant growth and development (Sistani et al. 2004; Egball and Power 1999). A number of studies have reported elevated levels of Cu, Zn, and Fe in runoff water collected from fields with increasing broiler litter application (Moore et al. 1998; Kingery et al. 1994; Van der watt et al. 1994).

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This study was to evaluate the enrichment trends of five plant micronutrients (Cu, Fe, Mn, Ni, Zn) and two potential pollutants (Pb, Cd) derived from long-term applied broiler litter and secondly to provide information that might help devise best management practices for manure uses.

MATERIALS AND METHODS

Soil samples were collected in triplicate from the 0 – 20 cm depth of the Hartselle series (fine-loamy, siliceous, subactive, thermic, Typic Hapludults) on a 3 – 8% slope in the Sand Mountain region of north Alabama. The soil is being managed for pasture and received annual broiler litter for 0, 5, 10, 15, 20 years at rates of 0, 2.27, 2.27, 3.63, and 1.36 Mg ha^{-1} yr^{-1} respectively. The samples were air-dried, ground to pass a 2-mm stainless steel sieve, and stored in plastic bags at room temperature. They were characterized (Table 1) for pH, electrical conductivity (EC), total C and N (Elementar Americas), NO_3-N and NH_4-N (Keeney and Nelson 1982), Ca, K, Mg, and Na (Mehlich 1984).

Table 1. Soil properties.

Year	pH	C	N	NH_4-N	NO_3-N	Ca	Mg	Na	K
		-------%	-------	----------	----------	mg kg^{-1}	----------	----------	----------
0	5.14	0.39	0.03	3.63	1.00	106	22.3	9.74	47.8
5	5.55	0.58	0.05	8.37	6.17	356	52.9	10.73	90.1
10	6.43	1.20	0.12	7.50	6.40	651	182.0	12.64	209.0
15	5.99	1.20	0.13	6.60	8.33	678	134.3	11.37	118.1
20	5.76	0.99	0.10	16.20	13.47	517	106.0	16.44	186.1

Trace elements and extractable Al were extracted with diethylenetriamine pentaacetic acid (DTPA) (Lindsay and Novell 1978). Polynomial contrast was performed to determine element trends (linear, quadratic, cubic and fourth order) as affected by years of applied litter.

RESULTS AND DISCUSSION

Soil pH increased following years of applied litter probably due to increase in the levels of added Ca, Mg, and K (Table 1). The average C/N ratio below 20 suggests faster mineralization rates of the litter materials in releasing nutrient elements. The EC values obtained were < 1.0 dSm^{-1} and this might suggest the lack of salinization following years of applied litter.

Table 2. Trace elements in soils.

Year	Fe	Mn	Zn	Cu	Pb	Cd	Ni
	mg kg^{-1}						
0	17.1d‡ (8.4)	5.26bc (2.1)	0.30c (0.11)	0.35c (0.11)	1.44a (0.18)	0.01a (0.008)	0.03a (0.03)
5	24.5cd (0.84)	2.08c (0.36)	1.54c (1.2)	0.57c (0.13)	1.36ab (0.08)	0.01a (0.005)	0.05a (0.02)
10	57.5b (1.2)	7.95ab (1.2)	2.66bc (0.77)	3.63bc (0.84)	1.24ab (0.18)	0.03a (0.004)	0.11a (0.06)
15	111.8a (1.4)	7.29ab (1.1)	9.27a (3.1)	8.93a (2.5)	0.95b (0.12)	0.11a (0.07)	0.25a (0.12)
20	44.9bc (1.1)	11.90a (2.8)	7.36ab (1.3)	7.23ab (1.3)	1.11ab (0.12)	0.03a (0.002)	0.22a (0.13)

‡Values with same letters within a column are not significantly different at $P < 0.05$ while values in parenthesis are standard deviation.

DTPA extracted elements (Table 2) showed a general increase with increased years of applications although no significant difference ($P < 0.05$) occurred between the 0 and 5 year time for Cu and Zn. Copper and Zn contents reported by Van der watt et al. (1994) for Georgia soils that have received poultry wastes between 16 and 18 years were consistent with our finding for soils that have received broiler litter for 15 and 20 years. Gaskin et al. (2003) reported similar results for soils that have received biosolids for 0, < 6, and > 6 years. Moore et al. (1998) reported low concentration of soluble Zn than Cu in runoff that has also received litter material. Statistically, there was no significant difference ($P <$ 0.05) for Cd and Ni with time of applied litter, although significant difference occurred for Fe, Mn, and Pb.

A metal enrichment factor (EF) was used to estimate the degree of metal enrichment due to applied litter. The degree to which the amended soils were enriched was determined by comparing normalized element contents and the control. The enrichment factor (EF) was determined as defined by Mbila et al. (2001).

$$EF = (Z/Al)_{amended}/(Z/Al)_{control}$$

Where:

EF = enrichment factor

Z = trace metal concentration (mg kg^{-1})

Al = total Al concentration (g kg^{-1})

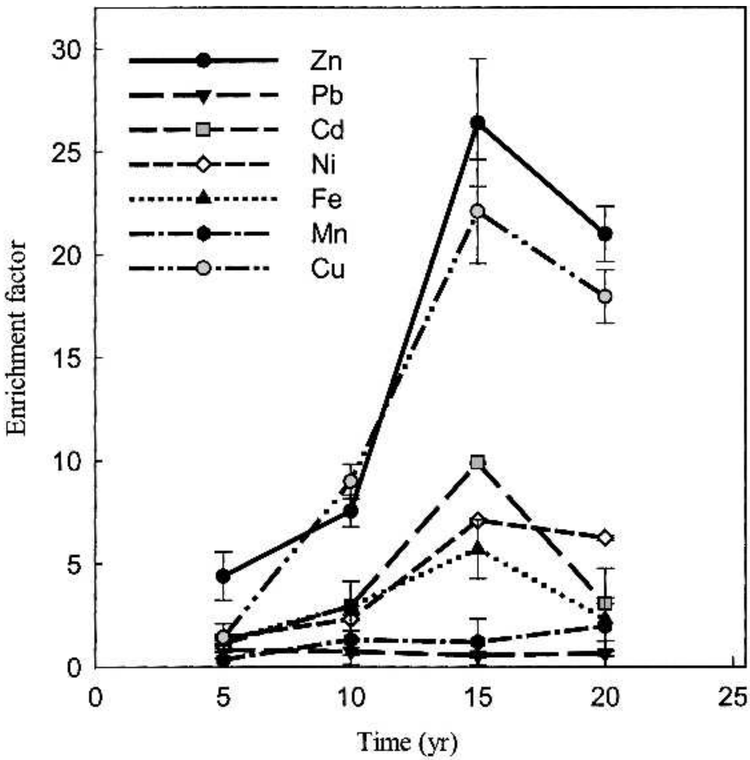

Figure 1. Trends in element enrichment.

Due to the relative immobility of Al in soils (Mbila et al. 2001), all metals were normalized against Al. As noted by Mbila et al. (2001), an EF value of ≤1 signifies lack of metal enrichment or depletion, whereas EF >1 denotes enrichment relative to the control. An enrichment factor is said to predict the net accumulation of a metal in soil after plant uptake when the amount of metal leached has been taken into account. Figure 1; suggest there was enrichment of elements (Fe, Cd, Cu, Ni, and Zn) in the soil resulting from long-term applied litter with the exception of Pb and Mn that showed depletion (EF <1). Also, the enrichment factor for Cd, Ni, Fe, doubled while that of Zn and Cu tripled between 5 and 15 years and decreased following 20 years of applied litter. As explained by Shuman and McCracken (1999), manure-derived Zn and Cu may not react with the soil if under no-tilled pasture management practices, leading to high surface accumulation. The enrichment factors calculated in sludge-amended soils of Nigeria (Mbila et al. 2001) showed soil surface horizons to be enriched with Cu and Zn but not Pb and Ni probably due to high pasture uptake. The decrease in EF following 20 years of applied litter in this study may be attributed to nutrient uptake or leaching given the fact that soils of this region are permeable and prone to high nutrient escape.

Because the treatments consisted of different values of an ordered variable, contrast analysis was performed, taking into account the differences in uniformity between the values (Hoshmand 1994). We examined if the treatment means were linearly related to the treatment variables in order to determine any significant curvature in mean trends by contrasting the DTPA extracted elements (Zn, Pb, Cd, Ni, Cu, Fe, Mn) with the cumulative effects of applied litter, using linear, cubic, quadratic and fourth order (quartic) models described below:

a). Linear model:

$$Z = a + b_1 x \qquad [1]$$

where:

Z = concentration in soil extract (mg kg^{-1})
a = constant
b_1 = slope of the curve
x = cumulative quantity of the element added

b). Quadratic model:

$$Z = a + b_1 x + cx^2 \qquad [2]$$

where:

c = curvature constant

c). Cubic model:

$$Z = a + b_1 x + cx^2 + dx^3 \qquad [3]$$

where:

d = partial coefficient

d). Quartic model:

$$Z = a + b_1 x + cx^2 + dx^3 + ex^4 \qquad [4]$$

where:

e = partial coefficient

Table 3. Trend analysis of trace elements.

Model	Fe	Mn	Zn	Cu	Pb	Cd	Ni
Linear	0.001*	0.004*	0.002*	0.001*	0.023*	0.175	0.043*
Quadratic	0.001*	0.147	0.900	0.760	0.504	0.417	0.979
Cubic	0.001*	0.455	0.135	0.041*	0.248	0.119	0.444
Order 4	0.042*	0.060	0.182	0.452	0.491	0.368	0.662

* Significant at $P < 0.05$.

Table 3, shows the significance of the model. The linear model (equation [1]) was significant for all elements determined except for Cd and thus best accomplished the trend analysis for elements in soils after years of applied litter. Barbarick and others (1997) reported similar findings for AB-DTPA extractable Cu, Ni, Mo, P, Pb, Cd, and Zn, with the exception of 4*M* HNO_3 extractable Cd, Mo, Ni and Pb, although the results gave smaller R^2 and larger SE values than the quadratic model. They (Barbarick et al. 1997) concluded that any deviation from the linear model could be attributed to plant uptake, elements transformed to less extractable or fixed forms, and movements beyond the 20cm depth. Although Fe satisfied all the models, its high fluctuation (i.e. increases and decreases) could be attributed to oxidation and reduction processes. From trend analysis, we concluded that metal accumulation in soils from long-term applied broiler litter does not always follow the linear trend.

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REFERENCES

Barbarick KA, Ippolito JA, Westfall DG (1997) Sewage biosolids cumulative effects on extractable-soil and grain elemental concentrations. J Environ Qual 26:1696-1702

Bitzer CC, Sims JT (1988) Estimating the availability of nitrogen in poultry manure through laboratory and field studies. J Environ Qual 17:47-54

Cabrera ML, Sims JT (2000) Beneficial use of poultry by-products: Challenges and opportunities. *In* J.F. Power and W.A. Dick (ed.) Land application of agricultural, industrial, and municipal by-products. Soil Sci Soc America, Madison, WI.

Eghball B, Power JF (1999) Phosphorus and nitrogen-based manure and compost applications: Corn production and phosphorus. Soil Sci Soc America J 63:895-901

Evers GW (1998) Comparison of broiler poultry litter and commercial fertilizer for coastal Bermudagrass production in southwest US. J Sustain Agric 4:55-77

Gaskin WJ, Brobst RB, Miller WP, Tollner EW (2003) Long-term biosolids application effects on metal concentrations in soil and Bermudagrass forage. J Environ Qual 32:146-152

Han FX, Kingery WL, Selim HM, Gerard PD (2000) Accumulation of heavy metals in a long-term poultry waste-amended soil. Soil Sci 165:260-268

Hoshmand AR (1994) Experimental research design and analysis: A practical approach for agricultural and natural science. CRC press, Boca Raton Florida

Jackson BP, Bertsch PM, Cabrera ML, Camberato JJ, Seaman JC, Wood CW (2003) Trace element speciation in poultry litter. J Environ Qual 32:535-540

Keeney DR, Nelson DW (1982) Nitrogen--Inorganic forms. p. 643-698. *In* A.L. Page et al. (ed.) Methods of soil analysis, Part 2, 2nd ed. Agronomy 9:

ASA, Madison,WI
Kpomblekou AK, Ankumah RO, Ajwa HA (2002) Trace and nontrace element contents of broiler litter. Commun Soil Plant Anal 33:1799-1811
Kingery WL, Wood CW, Delaney DP, Williams JC, Mullins GL (1994) Impact of long-term application of broiler litter on environmentally related soil properties. J Environ Qual 23:139-147
Lindsay WL, Norvell WA (1978) Development of a DTPA soil test for zinc, iron, manganese, and copper. Soil Sci Soc Am J 42:421-428
Mbila MO, Thompson ML, Mbagwu JSC, Laird DA (2001) Distribution and movement of sludge-derived trace metals in selected Nigerian soils. J Eviron Qual 30:1667-1674
Mehlich, A (1984) Mehlich 3 soil test extractant: A modification of the Mehlich 2 extractant. Commun Soil Sci Plant Anal 15:1409-1416
Miller WP, Martens DC, Zelazny LW, Kornegay ET (1986) Forms of solid phase copper in copper-enriched swine manure. J Environ Qual 15:69-72
Moore PA, Daniel TC, Gilmour JT, Shreve BR, Edwards DR Wood BH (1998) Decreasing metal runoff from poultry litter with aluminum sulfate. J Environ Qual 27:92-99
Nyakatawa EZ, Reddy KC, Brown GF (2001) Residual effect of poultry litter to cotton in conservation tillage systems on succeeding rye and corn. Field Crops Res 71:159- 171
Shuman LM, McCracken DV (1999) Tillage, lime, and poultry litter effects on soil zinc, manganese, and copper. Commun Soil Sci Plant Anal 30:1267-1277
Sistani KR, Brink GE, Adeli A, Tewolde H, Rowe DE (2004) Year-round soil nutrient dynamic from broiler litter application to three Bermudagrass cultivars. Agron J 96:525-530
Sims JT, Wolf DC (1994) Poultry waste management: Agricultural and environmental issues. Adv Agron 52:1-83
Van der Watt HV, Summer ME, Cabrera ML (1994) Bioavailability of copper, manganese, and zinc in poultry litter. J Environ Qual 23:43-49
Wood CW, Torbert HA, Delany DP (1993) Poultry litter as a fertilizer for Bermudagrass: effects on yield and quality. J Sustain Agric 3:21-37