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Heavy Metal (Cu, Fe and Zn) Pollution in Soils: Pig Waste Contribution in the Central Region of Ghana

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ABSTRACT

Pig wastes have been considered a source of heavy metal pollution in soils in communities in the Central Region of Ghana where pig production is a major occupation. The concentration of copper (Cu), iron (Fe) and zinc (Zn) in pig droppings and in soils from five pig waste dumping sites designated as NS, AM, AK, AD and NK and one non-dumping site (control) in the Assin South District were studied. The mean Cu concentration in the droppings varied from 12 mg kg^{-1} to 46 mg kg^{-1} and in the order NK>AM>NS>AK>AD. The mean Fe concentration in the droppings also ranged from 551 mg kg^{-1} to 657 mg kg^{-1} whilst the Zn concentration ranged from 55 mg kg^{-1} to 118 mg kg^{-1} and in the order AD>AM>NS>NK>AK and NS>NK>AM>AK>AD, respectively. The mean concentrations of extractable Cu, Fe and Zn in the soils from all the dumping sites were significantly ($P<0.05$) higher than the background value (control). The mean Cu concentration in the soils varied from 49 mg kg^{-1} to 70 mg kg^{-1}, whilst the Fe varied from 957 mg kg^{-1} to 1020 mg kg^{-1} and the Zn varied from 108 mg kg^{-1} to 204 mg kg^{-1} and the order of the variations differed from that of the pig droppings. The results of the quantification of the metal contamination in the soils from the dumping sites using geoaccumulation index indicated that at all the sites, the Cu pollution in the soils was moderate, the soils were almost not polluted by Fe and the Zn pollution was light.

Keywords: Heavy metal, Pollution, Dumping site, Assin south district, Geoaccumulation index

INTRODUCTION

In spite of its positive impact on poverty intervention, pig farming is not without some negative environmental implications. The waste from pig production is a major source of soil, water and air pollution [1]. Zhang et al. [2] observed that pig manure which is applied to agricultural lands with the aim of improving the soil fertility and organic matter content can result in nitrate and phosphate contamination of both surface and sub-surface waters. Cang et al. [3] also noted that application of pig manure to the soil can lead to accumulation of heavy metals in the soil. According to Atteia et al. [4], all year-round deposition of pig waste in terms of droppings and unused feed on available lands is a major source of pollution of the soil.

Heavy metals are elements that are characterized by relatively high density and high relative atomic weight with atomic number greater than 20 [5]. Chibuike and Obiora [6] noted that some heavy metals such as cobalt (Co), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni) and zinc (Zn) are required in minute quantities by organisms and excess amounts of these metals can become harmful to organisms. According to them, other heavy metals such as lead (Pb), cadmium (Cd), mercury (Hg) and arsenic (As) do not have any beneficial effect on organisms and are very harmful to both plants and animals. Djingova and Kuleff also observed that although plants require certain heavy metals for their growth and upkeep, excessive amounts of these metals can become toxic to plants [7].

According to Morris, a number of minerals including calcium, chloride, copper, iodine, iron, manganese, phosphorus, selenium, sodium and zinc in the form of feed additive are added routinely to the diet of pigs [8]. Conrad et al. observed that minerals serve many important functions in pigs, ranging from structural functions in the bone to a wide variety of chemical reactions essential for maintenance, growth, reproduction and lactation [9]. The copper, iron and zinc added to pig feed as growth promoters, essential minerals, electrolytes with antibiotics to treat diarrhea in young pigs, laxative agent for gestation and lactation and as trace mineral supplements could have, through the pigs' waste, the potential to increase the level of these heavy metals in the soil [10,11]. Jacela et al. noted that Cu and Zn play important role in physiological processes in pigs and the dietary Cu level of 5-10 ppm and Zn level of 50-125 ppm are generally enough to meet the pig's normal growth requirement [12]. Hill and Spears, however, observed that when they are deliberately added to feeds above the animals' requirements at high dietary levels, Cu (100-250 ppm) and Zn (2000-3000 ppm) can increase the growth performance of young pigs [13]. Iron is another vital component for proper growth in pigs, and Anderson and Easter noted that anemic condition such as hypochromic-microcytic anemia is generally associated with pigs deprived of iron in their diet or from their environment [14].

In spite of the positive impact on pig production, the use of these compounds at high levels result in contamination of soil where pigs manure is spread for extended periods [15]. This is because excess of these minerals (heavy metals) in the body of the pig could come out through their droppings into the soil. Hays observed that more than 95% of copper and zinc intake by pig is excreted via the faeces [16]. Awortwe also noted that in Ghana, for the same additive usage, the dietary levels of copper, iron and zinc differ from one farmer to another and in far excess than the recommended rate [17].

In Ghana, pig production decreased within the period of 1995 and 2006, due to an outbreak of African Swine Fever (ASF) [18]. However, there is an increase in pig's population by about 64.5% in Ghana since 2006 due to re-stocking of affected farms through the assistance of UN Food and Agricultural Organization [19]. Pig farming has thus been identified as a reliable source of poverty reduction and employment strategy [19] in Ghana and the Central Region in particular due to the prolific nature of pigs coupled with the high demand for pig products by all manner of people. Subsequently, the Central Region Development Commission (CEDECOM) in line with the Ghana Government's Poverty Reduction Strategy is pursuing commercial pig production projects in the Central Region to compliment the government's assisted pig farming projects in the region [20].

In view of this, large quantity of pig wastes (droppings and unused feed) are generated by these pig farming activities in the Central Region of Ghana but little is known about the exact residual levels of Cu, Zn and Fe in the pig droppings and the level of these metals in the soils at where the pig wastes are dumped. The study seeks to determine the levels of Cu, Fe and Zn concentration in the soils within the neighbourhood of pig waste dumping sites in the Central Region of Ghana. This would help in putting management practices in place to reduce any further accumulation of these metals in the soil.

MATERIALS AND METHODS

Study area

The study was conducted in the Assin South District in the Central Region of Ghana. The district is situated on latitude 5.5°N and longitude 1.03°W. The district falls within the Evergreen and Moist Semi-Deciduous Forest Zones. The rainfall pattern is bi-modal with the major rainy season starting from April to July while the minor rainy season starts from September to October. The district also experiences dry harmattan (North–East Trade) winds which blow from the Sahara Desert between November and February. The mean annual rainfall is between 1,250 mm and 2,000 mm and the mean temperature is 26°C [21].

The topography is undulating, with an average altitude of about 200 m above sea level with the highest rising to 611 m. The soil type is characterized by loamy soil and therefore suitable for crop production. However, much of the southern zone of the district is turned into animal rearing particularly pig production [22].

Experimental design

A field survey was conducted across the district to identify communities where pig productions were undertaken. A total of ten (10) pig farming communities within the district were visited out of which five (5) were selected. The selection criteria were population of pigs (150-500), the age of the farm (period of existence) (10-25 years) and the type of farming system (intensive). The selected farms were located at Nsuaem (NS), Assin Manso (AM), Assin Kyekyerew (AK), Adadietem (AD) and Nkanaso (NK) communities. The pig population and the age of the farms are presented in Table 1.

Sample collection

Samples of both fresh and old pig droppings were collected from the various farms. Also, a total of ten (10) disturbed and ten (10) core soil samples were randomly collected within 5 m radius away of pig waste (both dropping and unused pig feed) dumping site at each farm site. Same number of soil samples was also collected from a central

Table 1: Pig population and age of the various farms

Farm	Pig population	Age of the farm (years)
NS	150	11
AM	100	18
AK	450	20
AD	200	10
NK	500	25

community where there was no pig production activity (non-dumping site) to serve as control and was designated as O. The soil samples were collected within 0-20 cm depth and conveyed to the Soil Science Department Laboratory at University of Cape Coast, for the analysis of selected heavy metals (copper, iron and zinc) and other soil physico-chemical properties. Pig droppings were analysed in the same laboratory for same heavy metals. The copper, iron and zinc were selected because they were the elements the farmers usually used in their premix in the study area.

Sample analysis

The fresh pig dropping samples were oven-dried at 60°C and the old droppings and disturbed soil samples were air dried. The respective dried samples were ground into powder, homogenized and passed through a 2 mm sieve and stored in glass bottles at room temperature for subsequent analysis. Three replicate sub-samples were prepared for each sample.

Determination of some soil physico-chemical properties

The soil physico-chemical properties determined included texture, porosity, soil pH, organic carbon, total nitrogen, available phosphorus and exchangeable cations (Ca^{2+}, Mg^{2+}, K^+ and Na^+). The particle size distribution (texture) was determined by the hydrometer method [23]. The bulk density was determined using the core method [24] and the total porosity was calculated using the bulk density determined and a particle density of 2.65 Mg m^{-3} [25]. The soil pH was determined using a 1:2.5 (w/v) soil:water solution [26]. The organic carbon was determined using Walkley-Black method [27]. The total nitrogen was determined by Kjeldahl digestion method [28] and the available phosphorus was determined using the Bray-1 method [29]. The cation exchange capacity (CEC) of the soils was determined using ammonium acetate (NH_4OAc) extraction method as described by Rhoades [30]. The exchangeable cations were determined by adding 5 g of soil sample to 20 ml of 1M ammonium acetate solution in a 100 ml extracting bottle. The soil solution was filtered into a 100 ml volumetric flask and the filtrate was made up to 100 ml with ammonium acetate. The aliquots of the extract were used for the determination of Ca^{2+}, Mg^{2+}, K^+ and Na^+. The K^+ and Na^+ concentrations of the extracts then were determined using flame photometer and the appropriate calibration curve [31]. The Ca^{2+} and Mg^{2+} were determined using ethylene diaminetetra-acetic acid (EDTA) titration method [32].

Determination of heavy metals in the soil and the pig droppings

The digestion procedure as outlined by Allen et al. [33] was used to determine the heavy metals in both the soil and the pig droppings. A 0.4 g soil sample was weighed into a 100 ml Kjeldahl flask and 4.4 ml of digestion reagent was added to it. The mixture was digested at 360°C for 2 h, allowed to cool and filtered into a 100 ml volumetric flask and made up to the volume. A blank sample was also prepared in the same way but without soil sample. The filtrate was used for the Cu, Fe and Zn estimation using Perkin Elmer A Analyst 400 Atomic Absorption Spectrophotometer by following the standard methods [33,34]. The pig droppings were passed through an acid oxidation process to destroy the organic matter. The droppings were then digested and the heavy metals; Cu, Fe and Zn, were determined using the AAS [33,34] in a similar manner as used for the soil sample.

Quantification of soil pollution

The level of heavy metal pollution in the soils at the dumping sites were analysed and determined by geoaccumulation index (I_{geo}), which was established by Muller [35]. The Igeo was obtained by the ratio between the measured metal concentration (Cn) in the soil and the background value (Bn) of the metal in the soil. The computation of I_{geo} is thus given as [35]:

$$I_{geo}=\log_2 (C_n/1.5B_n)$$

In this study we used the metal concentration of the unpolluted soil (non-dumping site) [36] as the background value to calculate the I_{geo}. Muller [35] proposed seven classes of the Igeo and these classes are given in Table 2.

RESULTS AND DISCUSSION

Some soil physico-chemical properties at the study sites

Chibuike and Obiora [6] observed that soil properties affect heavy metal availability in diverse ways and hence the analysis of some soil physico-chemical properties at the study sites. Table 3 shows the soil physico-chemical properties of the pig wastes dumping sites as well as the non-dumping site which served as control (O). Though there were slight differences in the particle size distribution, the textural class at all the sites was sandy clay loam (SCL).

The total porosity at the sites ranged from 32% at the non-dumping (control) site to 50.7% at the AK site which had a high pig population of over 450 (indicating large quantity of pig waste generated per time) and had been in existence for over 20 years. There was significant ($P<0.05$) difference between the total porosity for both AK and AD sites on one hand and the other sites on another hand. However, there was no significant difference in total porosity among the O, NS, AM and NK sites. The high total porosity of over 50% at AK and AD dumping sites suggested that the soils of these sites were aerated. The soils at all the sites were acidic and similar to soils in most part the country. The acidity ranged from slightly acidic (6.47 pH) at AK, moderately acidic (5.77-5.8 pH) at O and AD, to strongly acidic (5.18-5.43 pH) at NS, AM and NK [37]. Though both the organic carbon and the total nitrogen at the non-dumping site were relatively lower than the dumping sites, there were no significant ($P<0.05$) differences between the non-dumping site (O) and the dumping sites. According to John et al. [38], the organic carbon contents at all the study sites were generally low because they were below 2% and this could be attributed to the leaching due to the porous nature of the soil. However, the soils could be considered fertile and could support plant growth because the organic carbon levels were higher than 0.75% [39]. The available phosphorus was significantly ($P<0.05$) higher (15.87 ppm) at the non-dumping site than the dumping sites and the least available phosphorus (5.75 ppm) was recorded at AK dumping site. The CEC at the non-dumping site was higher (14.81 cmolc kg^{-1}) than all the dumping sites and there was a significant ($P<0.05$) difference between the non-dumping site and the dumping sites. Similarly the exchangeable cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) at the non-dumping site were relatively higher than the dumping sites. This corroborated with observation by Hodges [40] that high CEC in soils held or buffered more cations. The NK farm had the highest number of pig population (500) and had been in existence for 25 years more than all the other farms suggesting that the NK dumping site had accumulated more wastes, but it had the least CEC in its soil which was significantly ($P<0.05$) different from the other dumping sites (Table 3). There was no significant difference in exchangeable cations among the dumping sites. Also apart from the Ca^{2+} there was no significant difference in exchangeable cations between the non-dumping site and the dumping sites. The low exchangeable cation concentrations could be attributed to the acidic nature of the soils at the sites that might lead to depletion of base cations because of the exchange between H^{+} and the bases [41].

Heavy metal concentration in pig droppings

Figure 1 shows the mean Cu, Fe and Zn concentrations in pig droppings from the various pig farm sites. From Figure 1a, the pig dropping copper concentrations from the farms are in the order NK>AM>NS>AK>AD. The highest concentration was 45.91 mg kg^{-1} whilst the lowest concentration 12.38 mg kg^{-1}. There was significant ($P<0.05$) difference between NK and the other farms. However, there was no significant difference between NS and AM farms, and between AK and AD farms.

The concentration of iron in pig droppings at the various farms are represented in Figure 1b. The iron concentration in the pig droppings however followed the order AD>AM>NS>NK>AK. The AD farm had the highest iron content 657.06 mg kg^{-1} in the pig droppings whilst AK farm had the lowest iron content of 551.11 kg mg^{-1}. There was no significant ($P<0.05$) difference between AD, AM and NS and between AK and NK.

Figure 1c also shows the concentration of zinc in the pig droppings at the various farms. The zinc concentrations in the pig droppings from the farms also are in the order NS>NK>AM>AK>AD. The NS had the highest (118.14 mg kg^{-1})

Table 2: Classification of geoaccumulation index (Igeo)

Geoaccumulation index	Classification	Level of pollution
$I_{geo} \leq 0$	0	Non pollution
$0<I_{geo} \leq 1$	1	Light-moderate
$1<I_{geo} \leq 2$	2	Moderate
$2<I_{geo} \leq 3$	3	Moderate-strong
$3<I_{geo} \leq 4$	4	Strong
$4<I_{geo} \leq 5$	5	Strong–extremely serious
$5<I_{geo} \leq 10$	6	Extremely serious

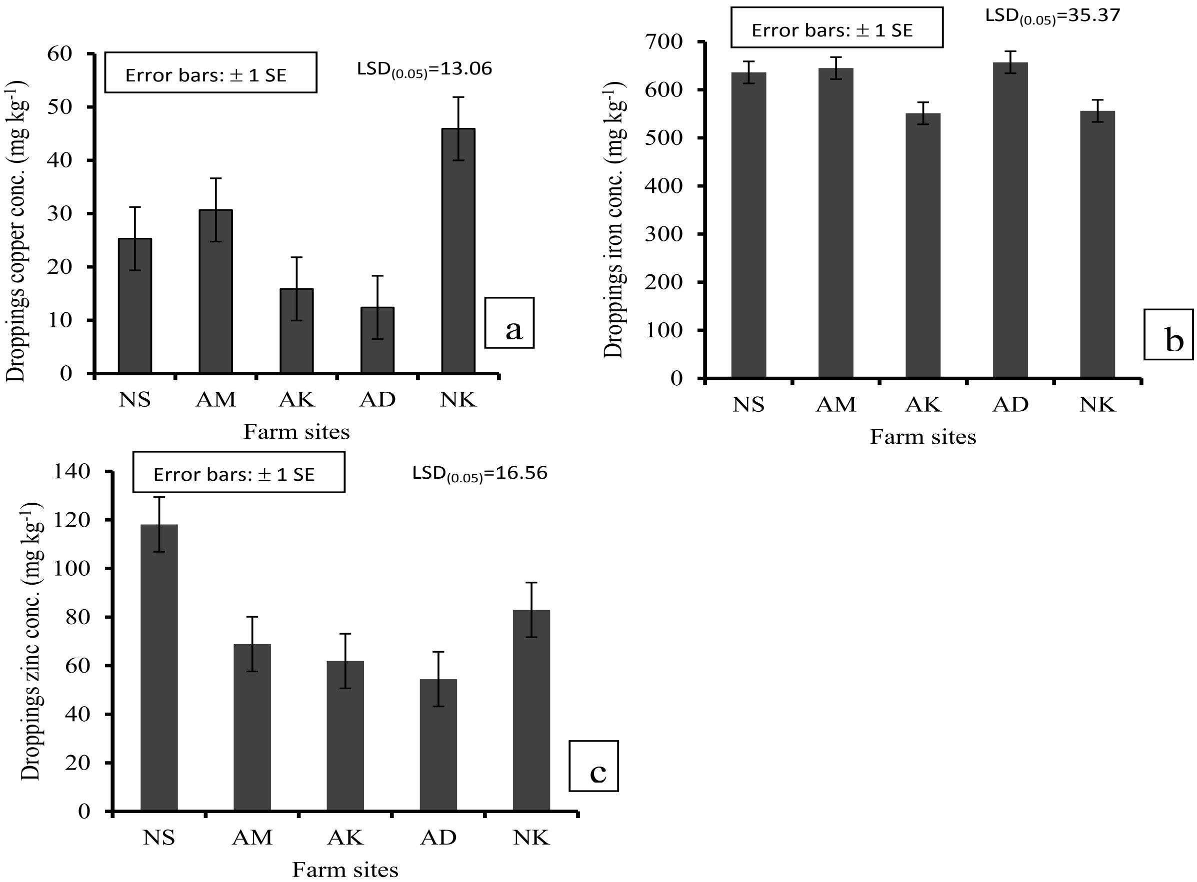

Figure 1: Concentration of (a) copper (b) iron (c) zinc in pig droppings from different farm sites

content of zinc in the dropping whilst AD had the lowest zinc content (54.46 mg kg^{-1}). There were significant ($P<0.05$) differences among the farms except between AM and AK.

The presence of Cu, Fe and Zn in the pig droppings corroborated with the statement by Willeke-Wetstein et al. [42] that some of the heavy metals taken in by the pigs are excreted via their faeces. McKean [43] also noted that the use of heavy metals in pig premix at high levels could result in environmental contamination of the ground where the pig droppings are spread. Therefore, the presence of these metals in the droppings suggested that the premix used by the pig farmers in the study area contained higher than required metals [12,17]. Again, the varied concentrations of the heavy metals in the droppings from the different sites suggested that farmers in the study area, depending on their individual interest, applied different levels of the metals in the formulation of their premix as noted by Awortwe [17].

Heavy metals concentration in soils at pig waste dumping sites and non-dumping site

Figure 2 shows the mean extractable Cu, Fe and Zn concentrations in soils from the various pig waste dumping (droppings and unused feed) and non-dumping (O) sites. The heavy metals concentration in soils at the dumping sites were significantly ($P<0.05$) higher than in soil from the non-dumping (O) site suggesting a release of these metals from the pig waste into the soil [43]. Also, the concentrations of these metals in the soils at each dumping site was significantly ($P<0.05$) higher than that in the droppings from the corresponding pig farm. This higher value could be attributed to the larger quantity of pig waste dumped and the length of time of the accumulation of the waste.

Figure 2a shows the concentration of extractable copper in soils at the dumping sites and the non-dumping site. The extractable copper concentrations in the soils from the dumping sites were between 63%-74% higher than the extractable copper concentration from the non-dumping site. Among the dumping sites, the extractable copper concentrations in the soils also varied from 49 mg kg^{-1} at AD site to 70 mg kg^{-1} at NK site. The extractable copper concentrations in the dumping site soils were in the order NK>NS>AK>AM>AD (Figure 2a). There was no significant difference between NK and NS sites, but there were significant ($P<0.05$) differences among the remaining sites. The high concentration of the extractable copper in AD site soil could be attributed to the high copper concentration in the droppings, the large quantities of waste generated due to the large size of stock and the length of time that the dumping site has been

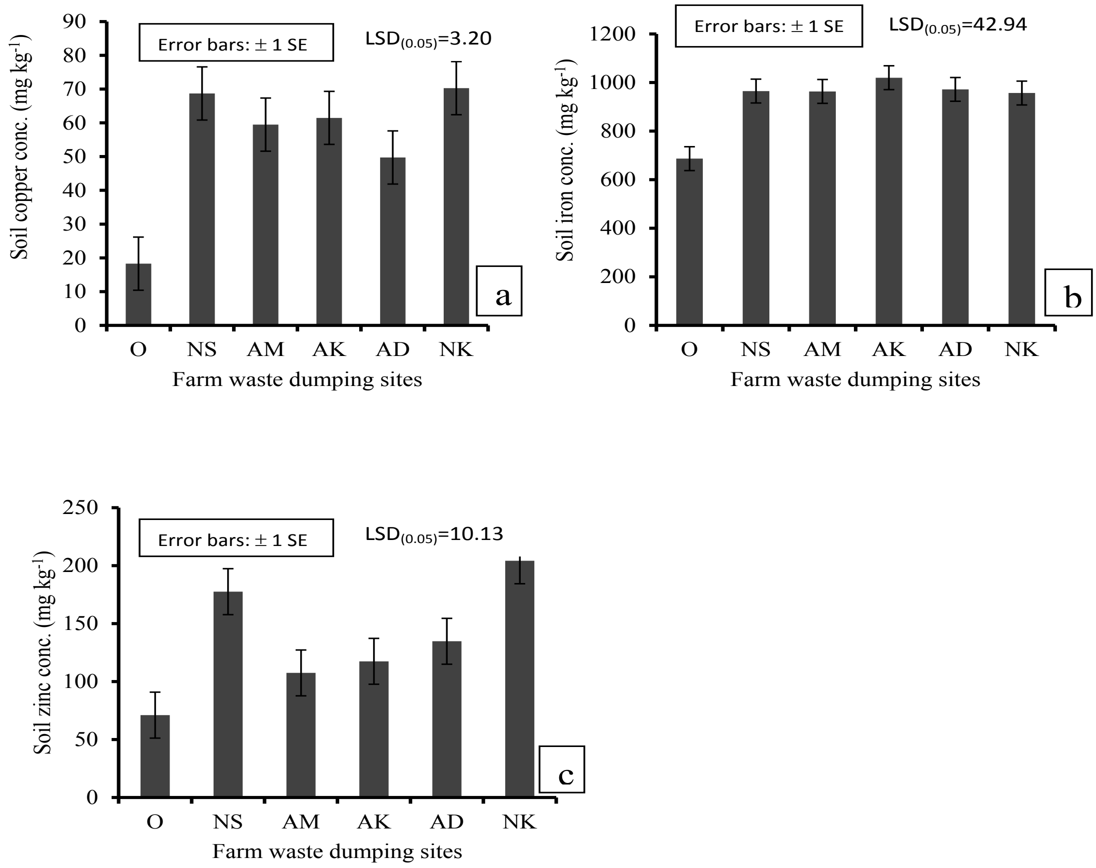

Figure 2: Comparison of (a) copper (b) iron (c) zinc concentration in soils from different pig waste dumping and non-dumping (o) sites

Table 3: Some physico-chemical properties of soils at the study area

Soil property	*Pig waste dumping and non-dumping sites						**Std. Error	LSD ($P \leq 0.05$)
	O	NS	AM	AK	AD	NK		
Textural class	***SCL	SCL	SCL	SCL	SCL	SCL	-	-
Total porosity (%)	32.00	37.30	35.30	50.70	50.00	39.30	5.06	15.60
pH	5.80	5.40	5.43	6.47	5.77	5.18	0.23	0.71
Org. Carbon (%)	1.62	1.72	1.86	1.95	1.74	1.77	0.22	0.67
Total N (%)	0.13	0.18	0.20	0.20	0.17	0.19	0.03	0.07
Av. P (ppm)	15.87	6.64	7.16	5.75	6.41	6.54	0.55	1.69
CEC ($cmol_c\ kg^{-1}$)	14.18	12.44	12.87	13.80	12.32	10.96	0.52	1.62
Ca^{2+} ($cmol_c\ kg^{-1}$)	7.05	5.43	4.97	5.40	5.36	5.16	0.38	1.16
Na^{+} ($cmol_c\ kg^{-1}$)	4.78	4.74	5.39	5.74	4.83	3.35	0.29	0.91
K^{+} ($cmol_c\ kg^{-1}$)	0.33	0.26	0.18	0.25	0.32	0.30	0.03	0.09
Mg^{2+} ($cmol_c\ kg^{-1}$)	2.02	2.01	2.33	2.41	1.81	2.15	0.30	0.93

*O=Non-dumping site (control); NS=Nsuaem; AM=Assin Manso; AK=Assin Kyekyewerew; AD=Adadietem and NK=Nkanaso dumping sites
** Std. Error=Standard Error
*** SCL=Sandy Clay Loam

in existence. The trend of the variation of the extractable copper in the soils at the sites was different from that of the droppings. This could be attributed to the quantity of waste (due to stock size) dumped or the age of the dumping site.

The extractable iron concentrations in the soils at the dumping sites and the non-dumping site are shown in Figure 2b. The concentrations in all the dumping sites were higher than the non-dumping site in a range of 28% and 33%. The order of the concentrations in the dumping sites soils was AK>AD>NS>AM>NK. The highest concentration (1020 mg kg^{-1}) at AK was significantly ($P<0.05$) different from the other sites which showed no significant differences among themselves. The order of variation of the extractable iron concentrations in the dumping sites did not follow a particular pattern relative to the concentrations in the droppings or the quantity of wastes dumped or the age of the dumping sites. However, it followed the reverse pattern of the available P at the sites (Table 3) and this corroborated with the observation by Hodges [40] that iron in acid soils readily complex with P thereby reducing the availability of both. The levels of iron concentration in the soils at the study area were however within the containment range of 20-2500 mg kg^{-1} [44].

Figure 2c also shows the extractable zinc concentrations in the soils at the dumping and non-dumping sites of the study area. The extractable zinc concentrations in the soils from all the dumping sites were between 34%-65% higher than the extractable zinc concentration from the non-dumping site. Among the dumping sites, the concentrations varied and were in the order of NK>NS>AD>AK>AM. Apart from AK and AM site, there was significant ($P<0.05$) difference in the extractable zinc concentrations among the sites. The extractable zinc concentration at NK site was higher (204.2 mg kg^{-1}) than the NS site even though the zinc concentration in the droppings from NK was lower than NS. This situation could be attributed to the large quantity of wastes generated due to the large size of stock and the age of the dumping site of NK relative to NS (Table 1). The low extractable zinc concentration (107.5 mg kg^{-1}) in soil from AM dumping site also could be attributed to the low quantity of generated wastes due to the relatively small size of its stock. Even though AK site had higher zinc concentration in the droppings, larger quantity of generated wastes (due to larger stock) and was older than the AD site, the AK site had lower extractable zinc concentration in its soil than AD. This situation could be attributed to the relatively more acidic nature of the soil at the AD site than the AK site, as Hodges [40] noted that zinc availability decreases with increasing soil pH. The zinc concentration at the study area however, was lower than the phytotoxicity level of 100–300 mg kg^{-1} [45,46].

Pollution quantification of the soils at the study area

The concentrations of the heavy metals studied (Cu, Fe and Zn) were above the background concentration level in the non-dumping site (control) soil and this suggested soil contamination of these metals. The levels of contamination of these heavy metals in the soils at the dumping sites were quantified using geoaccumulation index (I_{geo}) and the results are shown in Table 4.

The Cu contamination in the soils at all the dumping sites studied except AD site had I_{geo} between 1.12 and 1.36 which implied moderate pollution. The AD site had I_{geo} of 0.86 which indicated light pollution. The level of Cu contamination in the soils for agricultural use was slightly higher than observation by Su et al. [47] that in worldwide speaking, the content of Cu in most agricultural soils reached light pollution. From Table 4, the Fe contamination in the soils at all the dumping sites had negative I_{geo}, implying that they were almost not polluted by the Fe. This suggested that the pig production activity at the study site had very little or no Fe pollution effect on the soils. However, the content of Zn in the soils at all the dumping sites had I_{geo} less than 1 and ranged between 0.01 and 0.93. This implied that these sites were lightly polluted by Zn.

Table 4: Heavy metal contamination in soils at the pig waste dumping sites (I_{geo})

Dumping site	Heavy metal		
	Cu	Fe	Zn
NS	1.32	-0.09	0.74
AM	1.12	-0.10	0.01
AK	1.16	-0.02	0.14
AD	0.86	-0.08	0.34
NK	1.36	-0.01	0.94

CONCLUSION

The study revealed that the level of concentration of heavy metals (Cu, Fe and Zn) in pig droppings in the study area varied from one pig farm to the other. This indicated that the amount of heavy metals used in the premix formulation also differed from farmer to farmer. The level of the metal concentration in the soils also varied from one dumping site to the other but in different pattern from the droppings, primarily due to the influence of the quantity of pig waste dumped and the length of time the dumping sites has been in existence.

It was also revealed that the level of concentration of the heavy metals at all the dumping sites were significantly ($P<0.05$) higher than the non-dumping site (control). Even though the soils at the dumping sites were polluted with the metals compared with the background value in the control soil, the level of pollution was not serious that might require for immediate remediation. Whilst Cu pollution in the soils at almost all the dumping sites was moderate, the soils at the dumping sites were almost not polluted by Fe and Zn pollution in the soils at the sites was light. Therefore, the soils from these sites could be used for agricultural production since the soils were not strongly polluted. Examination of the levels of these metals in the crops grown at these sites and the effect on the yield is recommended for further studies.

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