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SPECIATION OF IRON AND ALUMINIUM IN DUMPSITE SOILS ASSOCIATED WITH FRUIT AND VEGETABLE WASTES IN YOLA, NIGERIA

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ABSTRACT

The increasing amounts of solid waste, particularly from fruits and vegetables, present major environmental challenges in rapidly urbanizing areas. This study was carried out to determine the different forms of iron (Fe) and aluminium (Al) in fruit and vegetable dumpsite soils in Yola, Nigeria. Soil samples were collected from three depths and analyzed for sodium pyrophosphate, ammonium oxalate, and citrate dithionite bicarbonate (CDB) extractable iron and aluminium. Results obtained revealed that there were highly significant ($P < 0.01$) differences between the interaction of dumpsite soils and sampling depths. The highest sodium pyrophosphate (pyro), ammonium oxalate (oxa) and citrate bicarbonate dithionite (CBD) extractable Fe of 32.58, 24.40, and 29.02 mg kg^{-1} were recorded by fruit dumpsite soil at 0-15 cm, vegetable dumpsite soil at 0-15 cm, and vegetable dumpsite soil at 30-60 cm depth, respectively. Also, highest pyro, oxa and CBD Al of 261.60, 198.18, and 185.40 mg kg^{-1} were recorded by fruit dumpsite soil at 0-15 cm, vegetable dumpsite soil at 30-60 cm, and vegetable dumpsite soil at 0-15 cm depth. A highly significant ($p<0.01$) positive correlation ($R = 0.83$) was observed between pyro Fe and Al. Significant negative correlation ($R = -0.90$) was obtained between oxa-Fe and CBD-Fe. The higher levels of sodium pyrophosphate-extractable Al and Fe in fruit dumpsites suggest increased bioavailability and mobility constituting a potential for leaching into groundwater. This study provides baseline data on dumpsite soils in Yola but does not account for temporal dynamics or variations in other regions.

KEYWORDS: Aluminium, Dumpsite soils, Fruit and vegetable wastes, Iron, Soil pollution

INTRODUCTION

Fruit and vegetable production is a vital sector of the agricultural industry, catering to the escalating global demand for fresh produce. The increasing amounts of solid waste, particularly from organic sources such as discarded fruits and vegetables, present major environmental challenges in rapidly urbanizing areas like Yola (Solomon et al., 2025; Koul *et al.*, 2022; Sam-Uroupa and Ogbeibu, 2020; Sharma *et al.,* 2021). Fruit and vegetable dumpsites are common in urban areas, where large quantities of organic waste from markets, processing plants, and households are disposed of (Alhassan *et al.*, 2021). The composition of these wastes, characterized by their high moisture content and readily decomposable organic matter, accelerates the release of nutrients and dissolved organic carbon into the surrounding soil environment upon disposal. This influx of organic matter significantly influences soil biogeochemical processes, particularly the speciation of iron and aluminium oxides, which are crucial in controlling the fate and transport of various contaminants (Zhu et al., 2025). The geochemistry of iron and aluminium oxides, which are important components of soil, is significantly influenced by these organic-rich leachates, which undergo complexation, dissolution, and redox transformations that dictate their ultimate speciation and mobility (Adewumi and Ajibade, 2015; Ojobor and Egbuchua, 2020).

Fruit and vegetable dump sites are areas where large quantities of organic waste are disposed and can lead to toxic levels of iron and aluminium in the soil due to the decomposition of organic matter. Although Iron is an essential nutrients for plant growth, high levels of this metal together with Al in soil can have detrimental effects on plant health and productivity. The presence of iron and aluminium oxides in these dumpsite soils can have a profound impact on the soil's structure and fertility, potentially altering the ecosystem and affecting plant growth. These metals can also leach into the soil and contaminate the surrounding environment, potentially affecting human health and the ecosystem (Ekere et al., 2020; Orimisan et al.,2024; Alengebawy et al., 2021).

Dumpsite soils containing fruit and vegetable wastes pose significant environmental and health risks due to the presence of heavy metals such as iron and aluminium. Iron and aluminium are essential elements that play critical functions in several biological activities (Zoroddu et al., 2019). However, excessive exposure to these elements can have adverse effects on human health and the environment. The levels of these elements in dumpsite soils can vary significantly depending on the type of waste disposed and the soil composition. These elements can leach into the soil and contaminate the surrounding environment, potentially affecting human health and the ecosystem. Therefore, understanding the different forms of iron and aluminium in dump site soil is essential for developing effective strategies to mitigate their potential negative impacts on plant health and the environment. (Parsafar et al., 2023).

MATERIALS AND METHODS

Location and Extent of Study Area

The study was carried out at the perishable crops market in Yola North Local Government Area of Adamawa

State, Nigeria. This market is located between Latitude 9.288'– 9.171 ' N and Longitude 12.433'- 12.26'E. This strategic location positioned it as a key destination for those seeking a rich commercial experience with the state capital. The market has separate areas for fruit and vegetable sellers; each section has its own dumpsite for daily wastes. These wastes decompose, and mixes with the surrounding soil forming a heap of soil that is regularly used as landfill and other purposes (Solomon et al., 2025).

Soil samples were collected from the study site using simple random sampling with a soil auger at different depths: 0-15 cm, 15-30 cm, and 30-60 cm. Samples were were collected from at least fifteen (15) point from each dumpsite and were made into three (3) composites for each depth, which serve as the replications for the entire experiment. The collected samples were air-dried to remove moisture. Large particles, stones, roots, and other debris were removed, and the samples were crushed using a mortar and pestle and sieved through a 2mm mesh sieve and analyzed for some physical and chemical properties.

Determination of Some physical and chemical properties

The particle size distribution of the soil was determined using the Bouyoucos hydrometer method (Bouyoucos, 1962). Soil core samplers were used to collect undisturbed soil to measure the bulk density in the laboratory, following the procedures outlined by Blake and Hartge (1986). This involved oven-drying the soil sample at 105 °C until it reached a constant weight, after which the dry weight of the soil was divided by the total volume of the sample.

Bulk density $(g\ cm^{-3}) = (weight\ of\ oven - dry\ soil\ (g)\ /\ (volume\ of\ soil\ (cm^3)$….eq. 1

Total porosity was estimated from the results of bulk density and particle density, assuming a particle density value of 2.65 $g\ m^{-3}$ (Agbenin, 1995) using the formula:

$$\text{Total porosity (\%)} = \left(1 - \frac{bulk\ density}{particle\ density}\right) X100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{eq. 2}$$

The soil pH was measured in a 1:2.5 soil-to-water ratio (Agbenin, 1995). The electrical conductivity (EC) of the soil was measured using a 1:2.5 soil/water ratio, as described by Ryan (2001). The soil organic carbon was determined using the Walkley and Black (1934) method and the value of organic matter was obtained by multiplying the organic carbon content of the soil by a factor of 1.724. based on the assumption that only 58 % of organic matter is organic carbon. Total nitrogen was determined by the micro Kjeldahl method (Bremner and Mul vaney, 1982). Available phosphorus was determined as described by Jou (1978) using the Bray-1 method (Bray and Kurtz, 1945). Exchangeable cations (Ca, Mg, K and Na) were determined using the NH_4OAc saturation method at pH 7.0 as described by Thomas (1982). Total exchangeable acidity (TEA) was determined as described by Thomas (1982). Effective cation exchange capacity was estimated by summing up the exchangeable cations and the total exchangeable acidity (Jou, 1978). while the percentage base saturation was calculated for both CEC (NH_4OAc) and ECEC from the formula: (Agbenin, 1995)

$$Base\ saturation\ (\%) = \frac{total\ exchangeable\ bases}{ECEC} X\ 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{eq.3}$$

Determination of the different extractable iron and aluminium

This involves the determination of three (3) different forms of extractable iron and aluminium: sodium pyrophosphate, ammonium oxalate, and citrate dithionite bicarbonate (CDB) extractable iron and aluminium.

Determination of sodium pyrophosphate extractable Fe and Al

Organically bound Fe and Al were extracted using 0.1M sodium pyrophosphate. 0.5 g of a soil sample that passed through a 1 mm mesh sieve was incubated overnight after adding 30 ml of 0.1 M $Na_4P_2O_7 \cdot 10\ H_2O$ at pH 10 for sixteen (16) hours (McKeague et al.,1971) Fe and Al in the extract were then determined using atomic absorption spectroscopy (AAS).

Determination of acid ammonium oxalate extractable Fe and Al

To determine the amount of amorphous iron (Fe) and aluminium (Al), 400 mg of ground soil, which was passed through a 1 mm mesh sieve, was placed in a 15 ml centrifuge tube. Then 10 ml of the 0.2M acidified Ammonium oxalate solution at pH 3.0 was added to the tube, and the tube was closed tightly. The samples were then maintained in the dark and placed in a reciprocal shaker for 4 hours as described by McKeague et al. (1971). Fe and Al in the extract were then determined using atomic absorption spectroscopy.

Determination of citrate dithionite bicarbonate extractable Fe and Al

To determine CDB extractable Fe and Al, the method described by McKeague et al. (1971) was adopted. 0.2 g of the soil sample was ground and passed through a 1mm-mesh sieve. The sample was placed into a 50-ml glass centrifuge tube, where it was combined with 25 ml of a 0.3 M sodium citrate solution and 3 ml of a 1 M sodium bicarbonate solution. The mixture was then heated to a temperature between 75 and 80°C, ensuring that it did not exceed this range. Then 1 g of solid dithionite was added, and the mixture was stirred constantly with a glass rod for one minute and then occasionally for 5 minutes. A second 1-g portion of Na-dithionite was added with stirring as before. A third 1-g portion was added with stirring. If a brown or red colour in the sample persists, the Na dithionite treatment is repeated. At the expiration of the 15-minute digestion period, a mixture comprising 5 ml of saturated sodium chloride solution and 5 ml of 100% acetone was introduced into the tube to facilitate flocculation. The clear supernatant is then carefully decanted into a 100-ml volumetric flask. Wash the residue twice with two 20 ml portions of 1N NaCl. The clear supernatant was filtered and combined with the solution in the same 100-ml volumetric flask and made up to volume with distilled water. Fe and Al in the extract were then determined using atomic absorption spectroscopy.

Experimental Design

The experiment was laid in a 3 X 2 factorial Randomized complete block design (RCBD) replicated three (3) times using three (3) levels of sampling depths and two (2) types of dumpsite soils to compare the different forms of Fe and Al in the dumpsite soils.

Data Analysis

Data obtained were subjected to analysis of variance (ANOVA) Significant means were separated using the Tukey honest significant difference test. Pearson's correlation analysis was performed to investigate the relationships between various soil properties and different forms of iron (Fe) and aluminium (Al). These analyses were conducted using the Statistical Analysis System (SAS) version 9.4.

RESULTS AND DISCUSSION

Physical and Chemical Properties of Fruit and Vegetable Dumpsite Soils

The results of the physical and chemical properties of the dumpsite soils are presented in Table 1. Data obtained indicate that the soil texture is predominantly sandy for both fruit and vegetable soils across all sampled depths. The highest sand content 80.80 % was recorded in vegetable dumpsite soil at 15-30 cm and 30- 60 cm depths. While slightly lower values were observed in the fruit dumpsite soil. Silt and clay contents are comparatively low, with fruit dumpsite soil recording the highest sit content of 19.20 % at 0-15 cm depth while the highest clay content of 8.00 % were recorded in vegetable dumpsite soil at 15- 30 cm. This may be due slower rate of decomposition of fruit wastes as well as it's the coarse and fibrous material which results in a silty and sandy texture. In contrast, vegetable waste decomposes quickly with easily degradable leafy materials, resulting in higher clay content, better porosity, and improved nutrient retention. This implies that the type of organic matter and its decomposition processes significantly affect soil physical properties and particle size distribution. Similarly, Tripathi and Misra (2012) opined that vegetable waste tends to decompose into finer particles, contributing to higher clay content due to its higher moisture retention properties. Leroy et al. (2008) asserts that the use of fruit waste compost can improve soil aeration and drainage. The bulk density values of about 1.61 to 1.66 g/cm³ were recorded across the dumpsite soils and sampling depths, suggesting moderate compaction typical of sandy soils, while total porosity ranges from approximately 37.20 % in fruit dumpsite soil at 30-60 cm depth % to nearly 39.20 % in vegetable dumpsite soil at 0-15 cm depth. supporting adequate air and water movement within the soil. The higher porosity recorded by the vegetable dumpsite may be attributed to its higher clay content. Islam et al. (2023); Amadi et al. (2024) reported that vegetable waste typically has a higher volatile matter content, which contributes to greater porosity as it decomposes more rapidly, creating air pockets in the soil.

Soil pH values lie in the slightly acidic to near-neutral range, from about 5.87 to 6.29 in fruit dumpsite soil at 0-15 cm and 15-30 cm depth respectively. depth which is generally favorable for nutrient availability and plant growth for both fruit and vegetable soils. This pH range is optimal for most crop product suggesting that nutrient availability may be favourable for plant growth (Mohammed and Mohammed 2012). Ogbemudia and Mbong (2013) observed that dumpsite soils mostly have low pH values leading high levels of heavy metals, which easily become bioavailable, posing health risks when taken up by plants during growth and development. Nta et al. (2020) reported that low pH can influence the mobility and solubility of heavy metals, potentially increasing their uptake by plants (Nta et al., 2020; Singh et al., 2017). However, these are fruit and vegetable market dumpsite soils, and the heavy metal load is not expected to be high as substantive amount of the waste are organic. Therefore, while the pH of of these dumpsites may support crop growth, it is crucial to monitor heavy metal concentrations to ensure food safety and soil quality (Jadoun and Singh, 2014). Electrical conductivity (EC) levels are low, below 0.35 dS m^{-1} irrespective of depth and dumpsite, indicating minimal salinity stress in the dumpsite soils. Organic carbon content ranges from 1.24 to 1.42 % and remains relatively stable across depths and the two dumpsite soils. This suggests moderate organic matter which is beneficial for soil fertility and structure. Musa et al. (2021) opined that the benefits of organic matter in soil cannot be over emphasized, noting that it enhance the structure of the soil.

Table 1: Physical and Chemical Properties of Fruit and Vegetable Dumpsite Soils

Dumpsite	FRUIT	VEG	FRUIT	VEG	FRUIT	VEG
	0-15 cm		15-30 cm		30-60 cm	
Sand (%)	75.20	79.20	77.80	80.80	80.32	80.80
Silt (%)	19.20	12.80	15.20	12.80	13.68	11.60
Clay (%)	5.60	8.00	7.00	6.40	6.00	7.60
Bulk D. (g cm^{-3})	1.66	1.61	1.62	1.65	1.66	1.62
Total porosity (%)	37.40	39.20	39.10	38.00	37.20	38.60
pH	5.87	6.23	6.29	6.06	6.15	6.16
EC (dS m^{-1})	0.30	0.28	0.29	0.34	0.30	0.26
Organic C (%)	1.38	1.39	1.37	1.24	1.33	1.42
Total nitrogen (%)	0.14	0.14	0.14	0.13	0.14	0.15
Avail. P (mg kg^{-1})	11.48	8.50	14.00	11.48	10.14	10.88
Ca^{2+} (cmol(+) kg^{-1})	6.06	7.93	6.26	6.02	4.84	7.80
Mg^{2+} (cmol(+) kg^{-1})	2.19	1.97	2.56	2.07	2.44	2.49
Na^{+} (cmol(+) kg^{-1})	0.29	0.33	0.34	0.23	0.22	0.38
K^{+} (cmol(+) kg^{-1})	0.59	0.66	0.56	0.54	0.61	0.67
TEB (cmol(+) kg^{-1})	9.13	10.89	9.72	8.85	8.11	11.34
TEA (cmol(+) kg^{-1})	2.75	2.60	3.23	3.11	3.45	4.10
ECEC (cmol(+) kg^{-1})	11.89	13.49	12.95	11.96	11.56	15.44
PBS (%)	76.87	80.57	74.92	73.76	69.79	73.20

FRUIT= Fruit dumpsite soil, VEG= Vegetable dumpsite soil, TEB= total exchangeable bases, TEA= total exchangeable acidity, ECEC= effective cation exchange capacity, PBS= percentage base satiration

This improvement leads to better moisture retention and aeration, which are both essential for healthy root development. Similarly, Asare and Száková (2023) reported that increased organic carbon content contributes to a favourable carbon-to-nitrogen (C/N) ratio. This equilibrium supports efficient mineralisation and nutrient cycling, ultimately enhancing soil health and promoting plant growth.Total nitrogen content is also fairly consistent across depths and dumpsite soils (Table 1). These values are moderate compared to the recommended range for agricultural soils of 0.15-0.3%. Chokor and Agbai (2014) reported that nitrogen concentrations at waste dumpsites can reach levels as high as 1.48% at the surface and decrease with both increasing depth and distance from the site. The nitrogen level in the present study may be linked to the high rate of decomposition of organic waste in the area.

Available phosphorus shows some variability, being higher in the fruit soil, particularly at the 15-30 cm depth (Table 1). This suggests differential nutrient cycling or inputs between the two dumpsites. Oketola and Akpotu (2015) reported a range of 5.10 to 15.10 mg/kg across different dumpsites in Aba, Nigeria. However, Obianefo et al. (2017) reported phosphorus levels between 0.041 and 4.07 mg/kg in Port Harcourt, Rivers state, Nigeria, suggesting that values recorded by both dumpsite soils in this study are higher than those in their studies. However, Amos-Tautua (2014) reported available phosphorus levels that ranged from 35.00 to 84.20 mg/kg, which are considerably higher than those found in this study. These are all indications that the nutrient content of a dumpsite soil is always a function of the type and amount of waste being deposited. Exchangeable calcium, magnesium, sodium, and potassium are present in moderate quantities (Table 1). Exchangeable calcium content was higher in the vegetable dumpsite soil, while potassium is slightly higher in the fruit dumpsite soil. TEB, TEA, and ECEC values suggest the moderate fertility status of the soils, indicative of reasonable nutrient holding capacity.The PBS values ranging from 69.79 % to 80.57 % in fruit dumpsite at 30-60 cm and vegetable dumpsite at 0-15 cm depth respectively. This suggests good buffering capacity against soil acidification and implies that a high proportion of the soil's exchange sites are occupied by nutrient cations rather than acidic ions, which positively influences nutrient availability and soil health.

Results of the physical and chemical properties of the dumpsites indicate that disposal of fruit and vegetable wastes play significant role in affecting the physical and chemical properties of dumpsite soils. Rapidly decomposing vegetable wastes increase clay content, porosity, and calcium levels, while fruit wastes increased silt and potassium contents. These help in maintaining soil fertility, improving soil structure, and providing support for smallholder crop production. However, the acidic pH observed emphasizes the importance of monitoring heavy metal solubility to protect soil quality.

Effects of Dumpsite Soils and Depth of Sampling on Some Extractable Forms of Fe and Al

Table 2 presents the effects of dumpsite soils and depth of sampling on some extractable forms of Fe and Al. The data obtained revealed highly significant ($P<0.01$) differences in sodium pyrophosphate, ammonium oxalate and CBD extractable Fe based on both dumpsite soil and sampling depths. Fruit dumpsite soil shows a significantly ($P<0.01$) higher concentration of sodium pyrophosphate Fe (24.36 mg/kg) than vegetable dumpsite soil (23.58 mg/kg). Similarly, fruit dumpsite soil recorded a higher concentration (175.15 mg/kg) of sodium pyrophosphate Al compared to vegetable dumpsite soil (175.19 mg/kg); however, these values are not significantly different from each other. Significant differences in extractable Fe and Al between fruit and vegetable dumpsite soils, as well as across sampling depths, highlight the complex interactions of organic matter, metal complexation, and soil geochemistry. The higher sodium pyrophosphate-extractable Fe in fruit dumpsite soil compared to vegetable soil suggests that fruit waste contributes more to organo-metal complex formation with Fe. This may be due to the slower decomposition of fibrous, polyphenol-rich fruit residues, which enhance stable complexation with organic ligands. While sodium pyrophosphate-extractable Al concentrations are high in both

Table 2: Effects of Dumpsite Soils and Depth of Sampling on Some Extractable Forms of Fe and Al

Dumpsite soils	Pyrophosphate Fe	Ammonium Oxalate Fe	CBD Fe	Pyrophosphate Al	Ammoniun Oxalate Al	CBD Al
			(mg/kg)			
Fruit	24.36a	14.86b	22.36b	175.15a	148.78b	148.86a
Vegetable	23.58b	15.96a	24.03a	175.19a	165.88a	152.67a
MSD	0.510	0.771	0.738	3.600	12.490	14.976
P of F	0.0067	0.0101	0.0005	0.9799	0.0122	0.583
Depth						
0-15	27.70a	20.97a	18.51b	237.62a	149.32b	175.65a
15-30	21.49c	12.18b	25.00a	153.71b	146.21b	127.86b
30-60	22.70b	13.06b	26.06a	134.16c	176.46a	148.79b
MSD	0.768	1.162	1.112	5.4239	18.821	22.566
P of F	<.0001	<.0001	<.0001	<.0001	0.0024	0.0006
Dumpsite soil X Depth	**	**	**	**	**	**
P of F	<.0001	<.0001	<.0001	<.0001	0.009	0.009

Means with the same letters in the same column are not significantly different at $P<0.05$, MSD: Minimum significant difference, P of F Probability value. ** = highly significant, $P< 0.01$

soils, the lack of significant difference suggests that Al complexation is more influenced by long-term soil processes rather than recent organic inputs. Rakhsh et al. (2020) opined that Al typically exists in stable mineral forms or resistant organometallic complexes. The effect of sampling depth reflects vertical variations in organic matter content and soil redox conditions, with surface layers exhibiting higher concentrations of organically complexed Fe and Al due to fresh organic inputs. With depth, reduced organic matter and changes in soil chemistry lower the extractable organo-metal forms. Aluko et al. (2024) reported similar findings and opined that higher concentrations of sodium pyrophosphate extracted Fe in fruit dumpsite soil may result from different organic matter compositions, soil pH and waste types affecting metal leaching and availability.

Ammonium Oxalate Fe was significantly ($P<0.01$) higher in vegetable dumpsite soil (15.96 mg/kg) than in fruit dumpsite soil (14.86 mg/kg). Interestingly, the behaviour of ammonium oxalate Al mirrored the patterns we observed with Fe, showcasing a compelling similarity in their trends. Vegetable dumpsite soil recorded significantly ($p<0.05$) ammonium oxalate Al value of 165.88 mg/kg compared to 148.78 mg/kg recorded by fruit dumpsite soil. Ammonium oxalate is specifically used to extract Fe/Al bound in poorly crystalline or amorphous iron oxides, its higher concentration in vegetable dumpsite soil may be due to enhanced mineral weathering driven by organic acids, increased microbial activity, and the formation of poorly crystalline iron and aluminum oxides as a result of the rapid decomposition of vegetable waste in contrast to the more stable mineral-organic complexes and the slower biogeochemical cycling characteristic of fruit dumpsite soils (Olatunji et al., 2015). The change may also relate to how effectively the vegetables absorb metals, resulting in a richer nutrient profile. Adu et al. (2022) suggested that vegetables can absorb higher levels of metals due to their growth conditions and root structures, resulting in increased concentrations in the soil when their residues are returned. Similarly, vegetable dumpsite soil shows a significantly ($P<0.01$) higher concentration of CBD extractable Fe (24.03 mg/kg) compared to fruit dumpsite soil (22.36 mg/kg). CBD Al exhibits trends that are similar to those observed with CBD. However, these values are not significantly different from each other. CBD extraction targets crystalline Fe /Al oxides, so differences in Fe concentrations may be linked to the production of more organic acids and other by-products during the decomposition of vegetable wastes, which affect the oxidation-reduction reactions in the soil as a result of the dynamic moisture and redox conditions in vegetable dumpsites also help the aging and crystallinity of iron oxides. Vegetable waste breaks down quickly, which speeds up the weathering of minerals. The fast decomposition creates organic acids that help dissolve primary iron minerals. These then form stable, crystalline iron oxides. They are not significantly influenced by recent organic matter, but are more shaped by long-term soil development and natural processes. However, the non-significant difference on CBD-extractable aluminium in both soils shows that aluminium oxides are more stable, suggesting that while vegetable waste helps form and build up crystalline iron oxides, the mineral makeup of aluminium oxides stays mostly the same, regardless of the type of dumpsite soil. These reactions can also facilitate the formation of crystalline iron oxides. As iron is released from decomposing vegetable matter, it may be more likely to precipitate as iron oxides in the soil. However, Nta et al. (2020) and Olakunle et al. (2018) assert that the soil physicochemical properties can influence metal solubility and bioavailability, resulting in higher extractable Fe levels in vegetable dumpsite soils.

Result based on sampling depths revealed highly significant differences ($P<0.01$) in sodium pyrophosphate, ammonium oxalate, and CBD extractable Fe/Al (Table 2). The highest concentration of Pyrophosphate extractable Fe of 27.70 mg/kg was recorded at a depth of 0-15 cm and was significantly ($P<0.01$) higher than the rest of the sampling depths. However, the lowest pyrophosphate-extractable iron value of 21.49 mg/kg was recorded at a depth of 15-30 cm, which was significantly lower than the 22.70 mg/kg recorded at the 30-60 cm depth. Similar to what was observed on pyrophosphate extractable Fe, the highest pyrophosphate Al of 7.62 mg/kg was recorded at 0-15 cm depth and was significantly higher than the rest of the sampling depths. There was a notable decrease in concentration as depth increased, with 15-30 cm recording 153.71 mg/kg, while the lowest value of 134.16 mg/kg was recorded at 30-60 cm. Higher pyrophosphate extractable Fe and Al at the 0-15 cm depth may be due to the surface soil being richer in organic matter, providing more room for Fe and Al to bind with humic substances, creating stable Fe-organic complexes. These complexes can accumulate in the upper layer, leading to higher concentrations of pyrophosphate-extractable Fe and Al. However, in the lower layers, Fe is less likely to form stable organic complexes due to the reduced presence of organic matter, leading to lower pyrophosphate-extractable Fe values. Cancelo-González et al. (2015) opined that the presence of amorphous oxides at the surface enhances the extractability of these metals, as they are more reactive compared to crystalline forms found deeper in the soil. Similarly, Gypser et al. (2019) reported that the interaction of these metals with fulvic and humic acids, derived from the decomposition of organic matter, further increases their availability at the surface. Results based on ammonium oxalate extractable Fe, the highest value of 20.97 mg/kg was recorded at a depth of 0-15 cm and was significantly different from the values at the other sampling depths. The study found that the lowest concentration of ammonium oxalate-extractable iron (Fe) was 12.18 mg/kg, recorded at a depth of 15-30 cm.This value was not significantly different from the 13.06 mg/kg measured at a depth of 30-60 cm. Higher ammonium oxalate extractable Fe at the soil surface may be due to the accumulation of non-crystalline and poorly crystalline forms of iron oxides that are often associated with organic matter and surface processes. These forms are more soluble in ammonium oxalate, resulting in higher extractable concentrations on the surface, where organic matter is more abundant and where weathering processes have concentrated iron. Olatunji et al. (2015) opined that the soil surface experiences significant weathering, which can release Fe from primary minerals into more soluble forms. The presence of organic acids from decomposing plant material enhances the solubility of Fe, making it more extractable in the upper layer. Conversely, the highest ammonium oxalate extractable Al of 176.46 mg/kg was recorded at 30- 60 cm depth and was significantly different from 149.32 and 146.21 mg/kg recorded at 0-15 and 15-30 cm depth, respectively. Higher ammonium oxalate extractable Al at the subsurface layers may be due to the leaching of Al from the surface layers downwards due to water movement through the soil profile. As water percolates through the soil, it can dissolve and transport Al ions deeper into the profile, where they accumulate. Olatunji et al. (2015) reported similar results and opined that the crystalline forms of Al oxides tend to be more stable and less soluble than those of Fe, making Al not readily available at the surface, but can accumulate in subsurface horizons where it is less affected by organic matter

Citrate bicarbonate dithionite extractable Fe/Al showed a highly significant (P<0.01) difference among the sampling depths (Table 2). The highest CBD Fe of 26.06 mg/kg was recorded at 30-60 cm depth, but was not significantly different from 25.00 mg/kg. However, it was highly significantly (P<0.01) different from 18.51 recorded at 0-15 cm depth. The highest CBD Fe at the subsurface may be due to the release of Fe from primary minerals through weathering, accumulating it in subsurface horizons where it forms stable oxides and hydroxides, which are less soluble and more resistant to further weathering, leading to higher concentrations with depth. Lei et al. (2022) and Fan et al. (2016) opined that subsurface layers may have finer textures that enhance the retention of Fe oxides. In contrast, the highest CBD extractable Al at the soil surface may be attributed to the higher organic matter content, which can be complex with Al ions, making them more extractable. Organic acids from decomposing plant material can enhance the solubility of Al, leading to higher concentrations at the surface. Contrary to what was observed on CBD Fe, the highest CBD Al of 175.65 mg/kg was recorded at 0-15 cm depth and was highly significantly (P<0.01) different from 127.86 and 148.79 mg/kg recorded at 15-30 and 30-60 cm depth, respectively (Table 2). Lei et al. (2022), Fan et al. (2016), and Olatunji et al. (2015) reported the higher concentration of CBD extractable Al at the surface and linked it to its limited mobility compared to Fe.

Interaction of Dumpsite Soils and Depth of Sampling on Some Extractable Forms of Fe

Table 3 and 4 presents interaction between dumpsite soils and sampling depth on sodium pyrophosphate, ammonium oxalate, and citrate bicarbonate dithionite extractable forms of Fe and Al, respectively. The results revealed a significant (P<0.01) interaction between dumpsite soils and sampling depth on sodium pyrophosphate, ammonium oxalate, and citrate bicarbonate dithionite extractable forms of Fe and Al. The highest sodium pyrophosphate, ammonium oxalate, and citrate bicarbonate dithionite extractable Fe of 32.58, 24.40, and 29.02 mg/kg, respectively, were recorded by fruit dumpsite soil at 0-15 cm, vegetable dumpsite soil at 0-15 cm, and vegetable dumpsite soil at 30-60 cm depth, respectively, and were significantly higher than that of the rest of the interactions (Table 3), the highest sodium pyrophosphate, ammonium oxalate, and citrate bicarbonate dithionite extractable Al of 261.60, 198.18, and 185.40 mg/kg were recorded by fruit dumpsite soil at 0-15 cm, vegetable dumpsite soil at 30-60 cm, and vegetable dumpsite soil at 0-15 cm depth, respectively, and were significantly higher than the rest of the interactions (Table 4). Higher sodium pyrophosphate extractable Fe and Al by fruit dumpsite soil at the 0-15 cm depth may be due to the surface soil being richer in organic matter, providing more room for Fe and Al to bind with humic substances, creating stable Fe-organic complexes. Higher levels of pyrophosphate-extractable iron and aluminium indicate a strong bond with decomposed organic matter. Ammonium oxalate-extractable iron and aluminium peak at varying depths, suggesting their movement is affected by organic acids and redox changes during waste decomposition. Also, CBD-extractable iron and aluminium accumulate at different depths, reflecting cycles of dissolution and redeposition tied to redox states and mineral transformations. This shows interplay between organic matter input, mineral cycling, and soil formation in tropical dumpsite soils. Cancelo-González et al. (2015) obtained similar results and opined that the presence of amorphous oxides at the surface enhances the extractability of these metals, as they are more reactive compared to crystalline forms found deeper in the soil. Similarly, Gypser et al. (2019) reported that the interaction of these metals with organic acids produced by plant roots further increases their availability at the surface.

Table 3: Interaction of Dumpsite Soils and Depth of Sampling on Some Extractable Forms of Fe

	Sodium Pyrophosphate Fe		**Ammonium oxalate Fe**		**Citrate Bicarbonate Dithionite Fe**	
	(mg/kg)					
Depth	Fruit Dumpsite Soil	Vegetable Dumpsite Soil	Fruit Dumpsite Soil	Vegetable Dumpsite Soil	Fruit Dumpsite Soil	Vegetable Dumpsite Soil
0-15	32.58a	22.83c	17.55b	24.40a	19.46d	17.57d
15-30	18.38d	24.60b	11.87d	12.51d	24.50bc	25.52b
30-60	22.11c	23.30bc	15.17c	10.97d	23.11c	29.02a
SE±	0.390		0.600		0.574	

Means with the same letters in the same row are not significantly different at P<0.05

Table 4: Interaction of Dumpsite Soils and Depth of Sampling on Some Extractable Forms of Al

	Pyrophosphate Al		Ammoniun oxalate Al		Citrate, Bicarbonate, Dithionite Al	
	(mg/kg)					
Depth	Fruit Dumpsite Soil	Vegetable Dumpsite Soil	Fruit Dumpsite Soil	Vegetable Dumpsite Soil	Fruit Dumpsite Soil	Vegetable Dumpsite Soil
0-15	261.60a	213.65b	154.65b	143.99b	165.90ab	185.40a
15-30	128.69d	178.73c	136.95b	155.47b	136.82bc	118.90c
30-60	135.15d	133.18d	154.73b	198.18a	143.86bc	153.72abc
SE±	2.7981		9.709		11.642	

Means with the same letters in the same row are not significantly different at $P<0.05$

Higher ammonium oxalate extractable Fe recorded by vegetable dumpsite soil at the soil surface may be due to the higher Fe absorption by vegetables and accumulation of non-crystalline and poorly crystalline forms of iron oxides that are often associated with organic matter and surface processes. Olatunji et al. (2015) reported similar findings and opined that the soil surface experiences significant weathering, which can release Fe from primary minerals into more soluble forms. However, the highest CBD Fe recorded by vegetable dumpsite soil at the subsurface may be due to the concentration of Fe in vegetable residue and the release of Fe from primary minerals through weathering. However, Lei et al. (2022) and Fan et al. (2016) opined that subsurface layers may have finer textures that enhance the retention of Fe oxides. In contrast, the highest ammonium oxalate extractable Al by Vegetable Dumpsite soil at the subsurface may be due to the leaching of Al from the surface layers downwards. Olatunji et al. (2015) reported similar results and opined that the crystalline forms of Al oxides tend to be more stable and less soluble than those of Fe. However, the highest CBD extractable Al at the soil surface may be attributed to the higher organic matter content, which can complex with Al ions, making them more extractable. Organic acids from decomposing plant material can enhance the solubility of Al, leading to higher concentrations at the surface.

Pearson's Correlation Coefficient of the Different Forms of Iron and Aluminium with Some Soil Properties

Results of the Pearson's correlation coefficient of the different forms of iron and Aluminium with some soil properties are presented in Table 5. Data revealed a highly significant ($p<0.01$) positive relationship between sodium pyrophosphate extractable Fe and Al, with an R value of 0.83. Sodium pyrophosphate mainly extracts organic-bound Fe and Al. This positive correlation suggests that both Fe and Al are strongly associated with organic matter in the dumpsite soils. This suggests that organic complexes in the soil may similarly bind Fe and Al, leading to their co-occurrence. Also, a highly significant ($p<0.01$) positive relationship was observed between ammonium oxalate Fe with sodium pyrophosphate Al and CBD Al with r values of 0.65 and 0.74, respectively. The positive correlations observed between ammonium oxalate-extractable iron (Fe) and both sodium pyrophosphate-extractable and CBD-extractable Al suggests a highly interconnected pedogenic system. Ammonium oxalate is used to extract poorly crystalline or amorphous Fe and Al oxides. Its strong correlation with sodium pyrophosphate-extractable aluminium, which assesses aluminium bound to organic matter, suggests that these amorphous iron oxides and aluminium-humus complexes are formed under similar conditions. This process is often driven by the presence of organic acids, which mobilise and complex both iron and aluminium, facilitating their co-precipitation or accumulation within the same soil horizons. Also, its correlation with CBD-extractable aluminium indicates that the factors controlling the formation of highly reactive amorphous iron oxides also play a vital role in the overall accumulation and distribution of all forms of aluminium oxides in the soil.

Table 5: Pearson Correlation Coefficients of Forms of extractable Fe and Al with some Soil Properties

	Pyro_Fe	Oxalate_Fe	CBD_Fe	Pyro_Al	Oxalate_Al	CBD_Al	Org.C	Tot. N	Av. P	Na	TEB	TEA	ECEC
Pyro_Fe	1	0.251	-0.360	0.833	0.151	0.262	-0.198	-0.144	-0.017	-0.062	-0.297	-0.325	-0.343
		0.314	0.143	<.0001	0.551	0.294	0.430	0.568	0.948	0.806	0.232	0.188	0.164
Oxalate_Fe		1	-0.896	0.646	-0.377	0.743	0.135	0.108	-0.455	0.032	-0.161	-0.522	-0.292
			<.0001	0.004	0.123	0.000	0.594	0.670	0.058	0.901	0.522	0.026	0.240
CBD_Fe			1	-0.731	0.587	-0.581	-0.168	-0.159	0.209	-0.046	0.378	0.672	0.515
				0.001	0.011	0.012	0.506	0.530	0.406	0.857	0.122	0.002	0.029
Pyro_Al				1	-0.209	0.471	-0.124	-0.098	-0.169	-0.062	-0.312	-0.573	-0.431
					0.406	0.049	0.624	0.699	0.504	0.807	0.208	0.013	0.074
Oxalate_Al					1	-0.025	-0.029	0.000	-0.193	0.147	0.370	0.320	0.401
						0.923	0.908	1.000	0.444	0.562	0.131	0.195	0.099
CBD_Al						1	0.178	0.112	-0.412	0.070	0.058	-0.042	0.035
							0.480	0.659	0.089	0.783	0.818	0.869	0.890
Org. C							1	0.979	0.090	0.526	0.052	-0.210	-0.022
								<.0001	0.723	0.025	0.839	0.402	0.930
Tot. N								1	0.108	0.406	-0.074	-0.251	-0.137
									0.669	0.094	0.771	0.315	0.587
Av. P									1	0.176	-0.027	0.239	0.050
										0.484	0.914	0.340	0.844
Na										1	0.570	-0.102	0.435
											0.014	0.687	0.071
TEB											1	0.471	0.963
												0.048	<.0001
TEA												1	0.692
													0.002
ECEC													1

Guhra et al. (2022) and Monterroso et al. (1999) concluded that the weathering, mobilization, and immobilisation of iron and aluminium are not independent processes and are regulated by a shared set of environmental and biogeochemical factors, such as soil pH, redox conditions, and the presence of organic ligands. However, a highly significant ($p<0.01$) negative relationship was observed between ammonium oxalate Fe with CBD Fe ($r=-0.90$) (Table 5). This strong negative correlation indicates that the Fe forms extracted by ammonium oxalate (poorly crystalline) and CBD (crystalline) are inversely related.

Soils with high amounts of poorly crystalline Fe oxides tend to have lower amounts of crystalline Fe oxides, which is typical of soils transforming amorphous to crystalline phases. On CBD Fe, results revealed a significant ($P<0.05$) positive relationship with oxalate Al, TEA and ECEC ($r=0.59$, 0.67 and 0.52) respectively. The positive correlation between CBD Fe and oxalate Al, TEA (total exchangeable acidity), and effective cation exchange capacity (ECEC) suggests that crystalline Fe oxides might contribute to higher soil acidity and cation exchange capacity. Crystalline Fe oxides can enhance soil surface charge, influencing the soil's ability to exchange cations. A significant but negative correlation was observed between CBD Fe with sodium pyrophosphate Al and CBD Al ($r= -0.73$ and -0.58). The negative correlation between CBD Fe and sodium pyrophosphate and Al suggests that soils rich in crystalline Fe oxides may have lower quantities of Al associated with organic matter or crystalline phases. This reflects distinct mineralogical or organic interactions, where high levels of crystalline Fe may reduce the binding capacity of Al to soil organic matter or Al oxides. However, sodium pyrophosphate extractable Al recorded a significant ($P<0.05$) positive correlation with CBD Al ($r = 0.47$). This positive relationship indicates some overlap between the organic-bound Al and the crystalline or less mobile forms of Al in the soil. This could suggest that a portion of Al exists in both organic and mineral forms, possibly due to dynamic soil processes like organic matter decomposition and Al solubility. While a significant ($P<0.05$) but negative relationship ($r= -0.57$) was observed between pyrophosphate extractable Al and TEA. The negative correlation suggests that higher levels of organic-bound Al might be associated with lower levels of soil acidity (as measured by TEA). Muindi et al. (2015) reported that organic matter might buffer soil acidity by binding Al, reducing its impact on soil pH and acidity. High levels of exchangeable Al, often found in acidic soils, can lead to increased acidity, which in turn affects the solubility and availability of Al in the soil solution. Also, Gruba and Mulder (2008) obtained similar findings and opined that as pH decreases, the competition between Al and H^+ ions increases, resulting in lower pyrophosphate-extractable Al due to enhanced binding to soil organic matter.

CONCLUSION

The study found only slight differences in the physical and chemical properties of the two dumpsite soils. Higher levels of sodium pyrophosphate extractable Al and Fe in fruit dumpsites suggest increased bioavailability and mobility of these forms of metals and their potential for leaching into groundwater or nearby water bodies, posing environmental risks. Also, variations in extractable Fe and Al across different depths highlight the importance of careful soil management, particularly in preventing metal mobilization. Significant variations observed on the interaction between dumpsite soils and sampling depth highlight important implications for environmental management practices regarding waste disposal sites, particularly concerning soil health and potential contamination issues. Therefore, proper waste management practices, such as composting and or waste treatment, can mitigate the negative effects of metal mobilityand improve soil health. However, soil management practices need to consider depth to address metal accumulation or contamination from dumpsites, as shallow ploughing may worsen Fe and Al mobility in the surface layers. Therefore, understanding these interactions is crucial for assessing nutrient availability in urban agricultural practices and environmental remediation efforts. Further studies should be carried out to study other heavy metals as well as the roles of microorganisms in metal cycling.

CONFLICT OF INTEREST

Authors declare that they don't have any conflict of interest

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REFERENCES

Adewumi, J. R. and Ajibade, F. O. (2015). The Pollution Effects of the Indiscriminate Disposal of Wastewater On Soil In A Semi-Urban Area. *Journal of Applied Sciences and Environmental Management*, *19*(3), 412-419.

Adu, A. A., Aderinola, O. J., Ogbe, A. A., T.F. (2022). Comparative Analysis of Heavy Metals

Concentration in Soil and Vegetable (Celosia argentea) Collected from Two Sampling Sites and Their Effect on the Plant's DNA Stability. International journal of research and review, 9(9):410-417. doi: 10.52403/ijrr.20220948

Agbenin, J. O. (1995). Phosphorus Sorption by Three Cultivated Savanna Alfisols as Influenced By pH. *Fertilizer research*, *44*(2), 107-112.

Alengebawy, A., Abdelkhalek, S. T., Qureshi, S. R., and Wang, M. Q. (2021). Heavy metals and pesticides toxicity in agricultural soil and plants: Ecological risks and human health implications. *Toxics*, *9*(3), 42.

Alhassan, A. B., Chiroma, A. M., Kundiri, A. M., Bababe, B., and Tekwa, I. J. (2021). Utilising urban refuse wastes as soil amendment in sub-Saharan Africa: Prospects and challenges in the Nigerian context. *Agro-Science*, *20*(3), 53-64.

Aluko, A. O. T., Obaseki, O. O. O., and Ibikunle, I. O. S. (2024). Impacts of dumpsites on heavy metal concentration in soil and vegetation in four dumpsites in Akure North, Ondo State.

Amadi, N., Yabrade, M., Nsan-Nicholas, O. H., and Gbosidom, V. L. (2024). Physiochemical properties of soil from waste dumpsites within Choba, Alakahia and Rumuosi Communities in Akpor, Rivers State, Nigeria. *Journal of Applied Sciences and Environmental Management*, *28*(7), 2217-2225.

Amos-Tautua, M. (2014). Assessment of phosphorus levels in soils of selected farms in Kogi state, Nigeria. International Journal of Scientific and Research Publications, 4(10), 1-5.

Asare, M. O., and Száková, J. (2023). Are anthropogenic soils from dumpsites suitable for arable fields? Evaluation of soil fertility and transfer of potentially toxic elements to plants. *Plant and Soil*, *486*(1), 307-322.

Blake, G. R., and Hartge, K. H. (1986). Bulk density. *Methods of soil analysis: Part 1 Physical and mineralogical methods*, *5*, 363-375.

Bouyoucos, G. J. (1962). Hydrometer method improved for making particle size analyses of soils 1. *Agronomy journal*, *54*(5), 464-465.

Bray, R. H., and Kurtz, L. T. (1945). Determination of total, organic, and available forms of phosphorus in soils. *Soil science*, *59*(1), 39-46.

Bremner, J. M., and Mulvaney, C. S. (1982). Nitrogen—total. *Methods of soil analysis: part 2 chemical and microbiological properties*, *9*, 595-624.

Cancelo-González, J., Prieto, D. M., Díaz-Fierros, F., and Barral, M. T. (2015). Lixiviación de Al y Fe en suelos sometidos a quemas controladas en laboratorio. *Spanish Journal of Soil Science*, *5*(1).

Chokor, J. U., and Agbai, W. P. (2014). Soil pollution as a function of distance from dumpsite. *Nigerian Journal of Life Sciences (ISSN: 2276-7029)*, *4*(2), 32-39.

Ekere, N. R., Ugbor, M. C. J., Ihedioha, J. N., Ukwueze, N. N., and Abugu, H. O. (2020). Ecological and potential health risk assessment of heavy metals in soils and food crops grown in abandoned urban open waste dumpsite. *Journal of Environmental Health Science and Engineering*, *18*, 711-721.

Fan, S. S., Chang, F. H., Hsueh, H. T., and Ko, T. H. (2016). Measurement of total free iron in soils by H2S chemisorption and comparison with the citrate bicarbonate dithionite method. *Journal of analytical methods in chemistry*, *2016*(1), 7213542.

Fink, J. R., Inda, A. V., Tiecher, T., and Barrón, V. (2016). Iron oxides and organic matter on soil phosphorus availability. *Ciencia e agrotecnologia*, *40*, 369-379.

Gruba, P., and Mulder, J. (2008). Relationship between aluminium in soils and soil water in mineral horizons of a range of acid forest soils. *Soil Science Society of America Journal*, *72*(4), 1150-1157.

Guhra, T., Stolze, K., and Totsche, K. U. (2022). Pathways of biogenically excreted organic matter into soil aggregates. *Soil Biology and Biochemistry*, *164*, 108483.

Gyabaah, E. K., Ofori, D. K., and Mensah, J. A. (2023). The impact of electrical conductivity (EC) on soil nutrient availability and crop performance in Ghana. *Journal of Soil Science and Agricultural Engineering*, 14(2), 123-130.

Gypser, S., Schütze, E., and Freese, D. (2019) Crystallization of single and binary iron-and aluminum hydroxides affect phosphorus desorption. *Journal of Plant Nutrition and Soil Science*, *182*(5), 741-750.

Islam, M. R., Wang, Q., Guo, Y., Wang, W., Sharmin, S., and Ebere Enyoh, C. (2023). Physico-chemical characterization of food wastes for potential soil application. *Processes*, *11*(1), 250.

Jadoun, R., and Singh, S. P. (2014). Assessment of heavy metal contamination in soil and its impact on plant growth. *International*

Journal of Environmental Sciences, 3(4), 307-314.

Juo, A. S. R. 1978. Selected methods for soil and plant analysis: IITA manual series, No. 1.

Koul, B., Yakoob, M., and Shah, M. P. (2022). Agricultural waste management strategies for environmental sustainability. *Environmental Research*, *206*, 112285.

Lei, L., Holásková, I., Thompson, J. A., and McDonald, L. M. (2022). Fe-Bound Organic Carbon and Sorption of Aromatic Dissolved Organic Carbon in Surface Soil: Comparing a Forest, a Cropland, and a Pasture Soil in the Central Appalachian Region, West Virginia, USA. Environments, 9(9), 113.

Leroy, B. L., Herath, M. S. K., De Neve, S., Gabriels, D., Bommele, L., Reheul, D., and Moens, M. (2008). Effect of vegetable, fruit and garden (VFG) waste compost on soil physical properties. *Compost Science and Utilization*, *16*(1), 43-51.

McKeague, J. A., Brydon, J. E., and Miles, N. M. (1971). Differentiation of forms of extractable iron and aluminum in soils. *Soil Science Society of America Journal*, *35*(1), 33-38.

Mohammed, A. A., and Mohammed, A. A. (2012). Effect of soil pH on citrus growth and yield. *Journal of Agricultural Science and Technology*, 4(1), 1-7.

Monterroso, C., Macías, F., Alvarez, E., and Fernández-Marcos, M. L. (1999). Geochemistry of aluminium and iron in mine soils from As Pontes, Galicia (NW Spain). *Water, Air, and Soil Pollution*, *110*(1), 81-102.

Muindi, E. M., Mrema, J. P., Semu, E., Mtakwa, P. W., Gachene, C. K., and MK, N. (2015). Lime-aluminium-phosphorus interactions in acid soils of the Kenya Highlands.

Musa, A. B., Abubakar, A. B., and Mustapha, H. (2021). Impact of organic matter on soil properties and crop yield in northern Nigeria. *Journal of Agricultural Science and Technology*, 13(2), 123-130.:

Nta, E. E., Edet, A. A., and Udo, E. J. (2020). Assessment of heavy metal contamination in soil and water samples around a dumpsite in Calabar, Nigeria. *Journal of Environmental Sciences and Natural Resources*, 12(1), 1-10.

Obianefo, C. A., Nwafor, P. N., and Obianefo, E. C. (2017). Physicochemical Characteristics of Soil from Selected Solid Waste Dump Sites in Port Harcourt, Rivers State, *Nigeria. Journal of Applied Sciences and Environmental Management*, 21(3), 59-68.

Ogbemudia, E. O., and Mbong, I. E. (2013). Assessment of heavy metal contamination in dumpsite soils and its implications on plant growth. International Journal of Environmental Sciences, 2(4), 307-314.

Oketola, A. A., and Akpotu, S. O. (2015). Assessment of solid waste and dumpsite leachate and topsoil. *Chemistry and ecology*, *31*(2), 134-146.

Ojobor, S. A., and Egbuchua, C. N. (2020). Use of Abattoir Wastewater Compost as Organic Fertilizer for Rice Production on a Utisol in Delta State, Nigeria. *Asian Journal of Agriculture and Rural Development*, *10*(2), 682-689.

Olakunle, I. A., Olanrewaju, T., and Olumuyiwa, A. (2018). Investigation of heavy metal content on dumpsites soil and vegetables grown: A case study of Ilesha metropolis, Nigeria. *International Journal of Advances in Scientific Research and Engineering*, *4*(12), 178-184.

Olatunji, O. O., Oyeyiola, Y., and Oyediran, G. O. (2015). Assessment of Dithionite and Oxalate Extractable Iron and Aluminium Oxides On A Landscape On Basement Complex Soil In South-Western Nigeria. *Open Journal of soil science*, *5*(11), 266-275.

Orimisan, A. E., Olarewaju, A. J., Babaniyi, B. R., and Olumuyiwa, A. O. (2024). Heavy metal content in dumpsite soils and vegetables: A case study of Ondo Town, Nigeria. *GSC Advanced Research and Reviews*, *19*(1), 097-104.

Parsafar, B., Ahmadi, M., Jahed Khaniki, G. R., Shariatifar, N., and Rahimi Foroushani, A. (2023). The impact of fruit and vegetable waste on economic loss estimation. *Global Journal Environmental Science and Management, 9*(4), 871-884.Ryan, J., Estefan, G., and Rashid, A. (2001). *Soil and plant analysis laboratory manual*. ICARDA.

Rakhsh, F., Golchin, A., Al Agha, A. B. and Nelson, P. N. (2020). Mineralization of organic carbon and formation of microbial biomass in soil: Effects of clay content and composition and the mechanisms involved. *Soil Biology and Biochemistry*, *151*, 108036.

Sam-Uroupa, E. R., and Ogbeibu, A. E. (2020). Effects of Solid Waste Disposal on the Receiving Soil Quality in Benin Metropolis, Nigeria. *Journal of Applied Sciences and*

Environmental Management, *24*(2), 393-401.

Sharma, P., and Kumar, S. (2021). Characterization and phytotoxicity assessment of organic pollutants in old and fresh municipal solid wastes at open dump site: A case study. *Environmental Technology and Innovation*, *24*, 101938.

Singh, M., Sarkar, B., Hussain, S., Ok, Y. S., Bolan, N. S., and Churchman, G. J. (2017). Influence of physico-chemical properties of soil clay fractions on the retention of dissolved organic carbon. *Environmental geochemistry and health*, *39*(6), 1335-1350.

Solomon, R. I., Simon, B., Musa, A. M., and Shehu, Y. (2025). Assessment of Inorganic Phosphorus Fractions of Fruit and Vegetable Dumpsite Soils as a Strategy for Mitigating Eutrophication Hazard. *Turkish Journal of Agriculture-Food Science and Technology*, *13*(4), 893-899.

Thomas, G. W. (1982). Exchangeable cations. *Methods of soil analysis: Part 2 chemical and microbiological properties*, *9*, 159-165.

Tripathi, A., and Misra, D. R. (2012). A study of physico-chemical properties and heavy metals in contaminated soils of municipal waste dumpsites at Allahabad, India. *International Journal of Environmental Sciences*, *2*(4), 2024-2033.

Vieira, C., and Droste, A. (2019). Biomonitors to evaluate the toxic potential of urban solid waste landfill leachate. *Revista Ambiente and Água*, *14*(2), e2326.

Walkley, A., and Black, I. A. (1934). An Examination of the Degtjareff Method for Determining Soil Organic Matter, and A Proposed Modification Of The Chromic Acid Titration Method. *Soil Science*, *37*(1), 29-38.

Zhu, S., Chen, J., Zhu, Y., Zhang, B., Jia, J., Pan, M., ... and Shen, Y. (2025). Influencing Factors of Hexavalent Chromium Speciation Transformation in Soil from a Northern China Chromium Slag Site. *Molecules*, *30*(15), 3076.

Zoroddu, M.A., Aaseth, J., Crisponi, G., Medici, S., Peana, M. and Nurchi, V.M (2019). The Essential Metals for Humans: A Brief Overview. *Journal of Inorganic Biochemistry*, *195*, 120-129.