

Investigation of trace element accumulation in Cockscomb (*Celosia argentea* Linn) grown in soil amended with chicken manure via some pollution indices

Oladele Abdulahi Oguntade (✉ deletade@yahoo.com)

Olabisi Onabanjo University College of Agricultural Sciences <https://orcid.org/0000-0002-0825-5089>

Nosiru Monday Yisa

Olabisi Onabanjo University College of Agricultural Sciences

Solomon Oladimeji Olagunju

Olabisi Onabanjo University College of Agricultural Sciences

Abiodun Oladipupo Joda

Olabisi Onabanjo University College of Agricultural Sciences

Kayode Matthew Adewusi

Olabisi Onabanjo University College of Agricultural Sciences

Richard Oluseyi Olayiwola

Olabisi Onabanjo University College of Agricultural Sciences

Research Article

Keywords: Bioaccumulation. *Celosia*. Chicken manure. Edible tissues. Trace element. Pollution indices. Soil

Posted Date: September 7th, 2022

DOI: <https://doi.org/10.21203/rs.3.rs-1897417/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License. [Read Full License](#)

Abstract

Trace elements such as Cadmium (Cd), Copper (Cu) and Manganese (Mn) in chicken manure can contaminate soil and bioaccumulate in edible tissues of plant resulting in food chain contamination. This study investigated the influence of chicken manure on trace element load of soil and accumulation in tissues of *Celosia argentea*. Potted soil, 5kg each was amended with either conventional chicken manure (CCM) or local chicken manure (LCM) at rates of 4, 6, 8, and 10 t ha⁻¹ and compared with control soil (no amendment). Treatments were replicated thrice in a Completely Randomized Design. Results showed that soil trace element pollution increased with rates of amendments. Pollution indices; contamination factor, degree of contamination, elemental pollution index, pollution load index and total contamination factor were significantly ($p \leq 0.001$) higher in soil amended with CCM than LCM. Bioaccumulation coefficients (BAC), bioaccumulation factor (BAF) and transfer factor (TF) of trace elements were higher in tissues of celosia grown with CCM than LCM. Contamination factor and PLI contributed most (92.7%) to soil's effective CEC. Above 4 t ha⁻¹, growth and yield were not significantly influenced by amendments. Root to shoot translocation of trace element was restricted by amendments. Potential risks of Cu and Mn accumulation in edible shoot of celosia are eminent above 6 t ha⁻¹ of the amendments.

Introduction

Meeting the demand for healthy and safe food has led to intensive organic farming where soil amendment with animal manure has become the global practice among farmers. Animal manure especially from poultry birds is a rich and good source of plant nutrients that are eco-friendly unlike inorganic fertilizers (Mortola et al. 2019; Oguntade et al. 2019). The consequence of over-utilization of animal manure on trace element/metal pollution of soil is of environmental concern. This is because of its associated threat to ecosystem and possible food chain contamination (Eugenio et al. 2020; Oguntade et al. 2020). Typically, the geochemical characteristic of soils generally possess some background levels of nutrient elements including trace metals which are inherent in them but often does not cause pollution. Application of chicken manure amendment to soils for organic farming is on the trend that requires attention to reduce soil pollution and minimize contamination of food crops. This is because livestock manure particularly from poultry have been recognized as a source of trace element/metal contaminants to agricultural soils while using it to improve soil fertility (Hanč et al. 2008; Luo et al. 2009; Oguntade et al. 2018). Hence, the unconscious deposition of trace metal contaminants in soils through over-fertilization with manure can increase trace element load of soil, contaminate food crops and endanger soil health and food chain (Khan et al. 2017; Kobierski et al. 2017).

Plant nutrients and trace metals found in chicken manure are primarily from the concentrate feeds, supplements and veterinary drugs given to the poultry birds (Nicholson et al. 1999; Adeli et al. 2007; Oguntade et al. 2019). More often, residues of trace metals in amended soils are dependent on the quality and quantity of manure applied (Nicholson et al. 1999). Studies have shown high levels of trace metals including arsenic, iron, zinc, copper, cadmium, chromium, manganese and lead in soils amended with chicken manure sourced from conventional battery cages (Zhang et al. 2012; Oguntade et al. 2017). Chicken manure is enriched with trace metals because some of the trace metals consumed by the chicken are not absorbed through the digestive system (Adeli et al. 2007). It is therefore obvious that manure from chicken birds raised under different management systems would have varying composition of trace element in their droppings because of the differences in constituent of the diet. Hence, variation in potential ecological risks of trace element in soil amended with such chicken manure and possible translocation into cultivated crop. However, little is documented on the environmental impact of trace metallic element in manure of local chicken raised under the free range system. Unlike conventionally raised chicken, free range locally raised chicken feed on food like insects, worms/larva and grasses from the natural or wild environment. The source of feed for local chicken perhaps is an indication of low level of trace metal in its manure and could reduce trace metal load in soils when used as amendment.

Copper (Cu), cadmium (Cd) and manganese (Mn) are among the trace metals found in feed additives and supplements given to chicken kept in battery cages for optimal production (Oguntade et al. 2018). These trace elements have densities greater than 5 g cm⁻³, long biological half-lives and can contaminate the food chain as toxic metals. Presence of elevated concentration of these trace elements in chicken manure could raise pollution load of soil when used as amendment. Soil amendment with livestock manure can enhance accumulation of trace metal in soils and subsequently become available for crop uptake (Antonious et al. 2012; Wajid et al. 2020; Ugulu et al. 2021). Since soil-plant movement of trace element is part of the natural means of nutrient cycling. However, consumption of crops that bio-accumulate trace metal in their edible part is one of the means of human exposure to toxic metals and could be life-threatening. This is because of the damaging effects toxic metal could have on body organs such as the brain, lungs, liver and kidney (Salem et al. 2000; Bando and Simon 2016; Shakoor et al. 2016).

Pollution load index is one of the means of assessing intensity of heavy metal pollution of soils (Jorfi et al. 2017). Pollution indices can give quantitative assessment of soil pollution level from build-up of trace element through agricultural activities (Shomar and Kalavrouziotis 2013). Furthermore, it is a useful tool for monitoring and evaluating the degree of soil contamination for predicting sustainability in agro-ecosystems (Kowalska et al. 2018). Several authors including (Cabrera et al. 1999); Hough et al. 2003; Kalavrouziotis and Koukoulakis 2012)

have developed various pollution indices for monitoring and assessing heavy metal risks in soil-plant system. Among these indices are; contamination factor (CF), degree of contamination (DC), elemental pollution index (EPI) and pollution load index (PLI). These indices are employed in order to quantitatively evaluate contamination levels of trace element in soil amended with chicken manure from different sources. The indicators will give insight on indices with the most influence on bioaccumulation and transfer of trace element in plant tissues. It may not be enough to assess pollution potential of soil amended with chicken manure without evaluating extraction and bioaccumulation potentials of celosia grown on such soil. This is germane when monitoring trace element transfer through soil-plants-human system. Studies have shown that crops growing on metal contaminated soils and environment cannot prevent metal uptake but can only restrict accumulation concentration in plant tissues depending on the metal (Baker 1981; Jamali et al. 2009; Oguntade et al. 2020). Properties such as Bioconcentration factor (BCF), Bioaccumulation coefficient (BAC) and Translocation factor (TF) are often used in evaluating toxic metal accumulation potentials of plants (Yoon et al. 2006; Bu-Olayan and Thomas 2009; Amin et al. 2018). These properties can therefore give insight into the potential ability of leafy vegetables such as celosia in translocating to edible shoot trace element taken up from manure amended soil. Knowledge provided thereof is expedient for valuable information on better management of chicken manure in promoting organic farming for healthy soil, improved yield and better quality of vegetables.

Cockscomb (*Celosia argentea* Linn) is a leafy vegetable that is rich in nutrients and other essential minerals required for balanced diet. Cockscomb is a popular vegetable among farmers in western Nigeria because of its fast growth rate and yield in addition to possibility of several harvests from a single plant (Oguntade et al. 2017; Oguntade et al. 2020). Celosia is one of the vegetables that has the potentials of accumulating trace metals in its edible and non-edible parts beyond allowable limits when grown on contaminated soils and environment (Alam et al. 2003; Yoon et al. 2006; Oguntade et al. 2020). Dietary consequence of consuming such vegetable can constitute health related problems. This study therefore aimed to investigate; (i) accumulation of trace element in soil amended with chicken manure from different sources, (ii) determine pollution index of chicken manure amended soil and (iii) bioaccumulation of the trace element in celosia tissues through transfer to edible and non-edible parts.

Materials And Methods

Study area, soil and chicken manure collection and preparation

The study was carried out at the Department of Crop Production, College of Agricultural Sciences, Ayetoro campus of Olabisi Onabanjo University, Nigeria. Soil used for the study was collected from the field lying on latitude 7.2339° N, longitude 3.0595° E and 109.75 m above sea level at Teaching and Research Farm of the College.

The soil was collected from 0-15 cm depth at the farm and air-dried for 7 days. Following drying, soil for the pot experiment was sieved with 7 mm mesh to remove stone and plant debris. Sub-sample for physicochemical analysis was however sieved with 2 mm mesh. Fresh droppings from layers bird in battery cages that serve as conventional chicken manure (CCM) were collected from the College's poultry farm. The layer birds from the college farm are on concentrate feed compounded from maize and groundnut cake (Oguntade et al. 2019). Similarly, droppings from local chicken (LCM) on free range system were collected within Ayetoro town from their coop/chicken pens. Collected droppings were air-dried for 4 weeks, crushed and sieved with 7 mm mesh. Sub-samples each of the soil and manure were subsequently taken for laboratory analysis.

Experimental setup

Buckets of 7 liter capacity each were filled with 5 kg soil homogenized with each type of amended chicken manure at the rate of 4, 6, 8 and 10 t ha⁻¹ on dry weight (*d/w*) basis. The control treatment did not receive any amendment (no fertilization). The study was a factorial experiment fitted into a completely randomized design (CRD) and replicated three times. The amended potted soils were left for two weeks prior to sowing of cockscomb (*Celosia argentea*) seeds. Seedlings of the leafy vegetable were thinned to one stand per pot 2 weeks after sowing (WAS). Each pot was watered with 250 mL of fresh water every other day for the first 3 weeks and thereafter every day until 6 WAS when plants were harvested. Weeds from each pot were removed manually and returned in-situ per pot. At harvesting, plant height, numbers of leave and primary branches per plant were recorded. Plants samples were thereafter separated into their edible (shoot) and non-edible (root) parts. Each plant part was separately cleaned with running tap water, briskly rinsed with distilled water to remove adhered particles, air-dried and fresh weights determined. Plant samples were later oven-dried at 65 °C to constant weight for determination of dry weight and then ground for chemical analysis. Sub-samples of soils from each pot were also taken for laboratory analysis.

Chicken manure analysis

The pH of the chicken manure was determined with glass electrode pH meter. Concentrations of calcium (Ca), magnesium (Mg), potassium (K), sodium (Na) as well as copper (Cu), iron (Fe), manganese (Mn) Zinc (Zn) cobalt (Co), nickel (Ni), chromium (Cr), cadmium (Cd) and lead

(Pb) were determined following aqua regia digestion. The analyses were carried out with the use of atomic absorption spectrophotometer, AAS (Buck Scientific 210VGP Model, Inc., East Norwalk, CT, USA) (Hseu et al. 2002; Sastre et al., 2002; Udo et al., 2009). Total Organic carbon (OC) was determined by wet oxidation method (Nelson and Sommer 1996) and nitrogen (N) by Kjeldahl method (Bremner and Mulvaney 1982). Phosphorus (P) content was determined by colourimetric method (Nelson and Sommers 1996).

Soil analysis

The soil pH was determined with glass electrode pH meter in 1:2 soil/water suspension (McLean et al., 1982). Exchangeable bases (Ca^{2+} , Mg^{2+} , K^{+} and Na^{+}) in the soil were extracted with 1 N ammonium acetate solution. Content of Ca^{2+} and Mg^{2+} were determined with AAS while K^{+} and Na^{+} were read on flame photometer. The soil exchangeable acidity ($\text{Al}^{3+} + \text{H}^{+}$) was extracted with 1 N KCl solution and determined by titration method (Anderson and Ingram 1993). Effective cation exchange capacity (ECEC) was estimated as addition of exchangeable bases and acidity. Base saturation (BS) was calculated in percentage as the ratio of exchangeable bases to ECEC according to Udo et al. (2009). Total Organic carbon was determined by oxidation method (Walkley and Black 1934), while total N was determined by macro-Kjeldahl method (Bremner and Mulvaney 1982). Extractable P was determined by Bray-1 method (Nelson and Sommers 1996). Particle size analysis of the soil was determined by the hydrometer method (Bouyoucos 1962). Trace elements in soil samples were digested with 2:1 (v/v) mixture of HNO_3 - HClO_4 acids aqua regia. Subsample (0.5 g) of the soil was weighed in a 100 mL digestion tube. Then, 10 mL of the aqua regia was added. The acid digestion was conducted at 150 °C for the first 90 minutes after which 2 mL concentrated HCl was added. Following addition of the conc. HCl, temperature of the digester was raised to 230 °C for another 30 minutes. After digestion, the aliquot in digestion tubes were allowed to cool down at room temperature, filtered (Whatman no. 41) into a 50 mL volumetric flask and made up to mark with distilled water. Trace elements (Cu, Fe, Mn, Zn, Co, Ni, Cr, Cd and Pb) concentration in the analyte was then measured with the use of AAS (Hseu et al. 2002; Sastre et al. 2002; Udo et al. 2009).

Plant analysis

Plant samples (0.5 g) were digested with 10 ml concentrated nitric (HNO_3) and perchloric (HClO_4) acids (2:1 v/v) for the first 90 minutes at 150 °C. Thereafter, 2 mL concentrated HCl was added to the digest and the temperature was raised to 230 °C for the next 30 minutes. Digested samples were cooled down at room temperature, digest transferred to 50 mL volumetric flask and diluted to volume with deionized water. The total content of Cu, Cd and Mn in the digest was then determined by AAS (Buck Scientific 210 VGP model, Inc., East Norwalk, CT, USA) (Hseu et al. 2002; Sastre et al. 2002; Udo et al. 2009). Trace element uptake by the vegetable was estimated as the product of concentration of each element in celosia tissue and its dry weight (Oguntade et al. 2015).

Soil contamination measurement

Contamination factor (CF)

The soil contamination or pollution factor was determined according to the equation (Håkanson 1980); $\text{CF} = \frac{C_{\text{metal}}}{C_{\text{bkg}}}$ Equation(1)

where C metal is the concentration (mg kg^{-1}) of a given trace metal in soil and C bkg is the background or preindustrial concentrations (mg kg^{-1}). For the concentration of metals in an uncontaminated soil, we adopted values reported by Turekian and Wedepohl (1961) for carbonate soils with similar sedimentary origin. The geochemical background concentration values of Cd, Cu and Mn were; 0.035, 4.0 and 1100.0 mg kg^{-1} , respectively (Turekian and Wedepohl 1961). The selected metals were among trace elements found in drugs and supplements given to the conventionally raised chicken (Oguntade et al. 2019), residues of which might be in the amended soil.

Degree of contamination (DC)

Degree of contamination of the soil by the selected trace metal was calculated as the sum of the CFs, according to Fiori et al. (2013) as follows:

$$\text{DC} = \sum \text{CF} \text{ Equation (2)}$$

The degree of soil contamination has been categorized into four as follows depending on intensity. Low $\text{CF} < 1$; moderate $1 < \text{CF} < 3$; considerable $3 < \text{CF} < 6$; high $\text{CF} > 6$ (Gong et al. 2008; Islam et al. 2015).

Total contamination factor (TCF)

The $\text{TCF} = (M1 + M2 + M3 + \dots Mn) / (M1r + M2r + M3r + \dots Mnr)$ Equation (3) where; $M1$,

$M2$, $M3 + \dots Mn$ represents the selected trace metals, ($M1r + M2r + M3r + \dots Mnr$) are the corresponding reference values of the metals with n as the number of analyzed trace metals (mg kg^{-1}) (Shomar and Kalavrouziotis 2013).

Elemental pollution index (EPI)

The EPI was calculated as follows; $EPI = n\sqrt{M1 \times M2 \times M3 \dots \times Mn}$ Equation (4) where; $M1, M2, M3, \dots, Mn$, represents the selected trace metals [19]

Pollution load index (PLI)

The PLI was calculated according to (Tomlinson et al. 1980) as;

$$PLI = n\sqrt{CF1 \times CF2 \times CF3 \dots \times CFn} \text{ Equation (5)}$$

where; n is the number of metals, while $CF1, CF2$ and $CF3 \dots CFn$ are contamination factors of the selected metals. According to Tomlinson et al. (1980), pollution levels are categorized as follows; no contamination ($PLI < 1$); moderate contamination ($1 \sim 2$); severe contamination ($2 \sim 5$); extreme contamination ($PLI \geq 5$).

Phytoextraction efficiency

In order to determine phytoextraction potential of trace elements by *Celosia argentea* grown on soil amended with chicken manure, the plant Bioconcentration factor (BCF), Bioaccumulation coefficient (BAC) and Translocation factor (TF) were calculated (Baker 1981; Bu-Olayan and Thomas 2009; Jamali et al. 2009; Amin et al. 2018).

Bioconcentration factor was calculated as; $BCF = \frac{C_{root}}{C_{soil}}$ Equation (6)

Bioaccumulation coefficient was calculated as; $BAC = \frac{C_{shoot}}{C_{soil}}$ Equation (7)

Translocation factor was calculated as; $TF = \frac{C_{shoot}}{C_{root}}$ Equation.....(8) where; C_{root} , C_{shoot} and C_{soil} are concentrations (mg kg^{-1}) of trace metals in root, shoot and soil, respectively.

Statistical analysis

The square root transformation was used to transform count data to satisfy normality and homoscedasticity. Thereafter, all data generated was subjected to one-way analysis of variance (ANOVA). Significant treatment means were separated by Fischer's protected Least Significant Difference (LSD) at 5% level of probability. The simple linear regression model was used to test the relationships among the soil properties, pollution indices and phytoextraction efficiency of the celosia. In addition, the regression was conducted to identify indices that contributed most to trace element pollution of soil and bioavailability in celosia tissues. Pearson's moment correlation analysis (r) was also carried out to measure the strength of the relationships between the selected soil chemical properties, growth and yield attributes, trace element concentration and bioavailability in plant tissues. The analyses were performed using GenStat software package 12th Edition (PC/Windows Vista) (Payne et al. 2009).

Results

Physicochemical characteristics of soil and chicken manure

The soil used in this study was moderately acidic with a loamy sand texture (Table 1). The contents of Co, Cr and Pb were below detection limits in both the soil and chicken manure. Chemical composition of the chicken manure showed that pH of the CCM was higher than that of the LCM (Table 1). Calcium and Mg were more than two folds higher in conventional than local manure. Potassium content in the CCM was also higher than in the LCM but Na in LCM was almost double the content in CCM. Total organic carbon was higher in CCM than in LCM and vice versa for total N. The C/N ratio of the CCM was higher than that of the LCM. Phosphorus content in CCM was more than double that of the LCM. Manganese and Cu contents were more than four folds higher in CCM than LCM. The contents of Zn and Cd were also higher in CCM than LCM. Among the selected trace elements only Fe and Ni were higher in LCM than CCM. Iron was more than 7 folds higher in LCM than CCM while Ni was 43.9% higher in LCM than CCM (Table 1).

Effects of chicken manure amendments on soil chemical properties

The chemical properties of the soil except Mg, increased significantly in soil amended with CCM over LCM (Table 2). Generally, the soil chemical properties increased significantly with manure rate. The interaction of sources and rates of manure was also significant on the soil chemical properties except for exchangeable acidity and Mg (Table 2, Figs. 1, & 2). That is, the sources and the rate affected the soil chemical properties, the effects of which depended on the rate of manure amendment. Across rates, the soil chemical properties were significantly higher in soil amended with CCM than LCM except for pH, ECEC and total N at 10, 4 and 6 t ha⁻¹, respectively (Figs. 1 a, c & d). In a similar trend, the trace elements (Cu, Mn, Zn) significantly increased with manure rates and were higher in soil amended with CCM than LCM (Figs.

2a, b & c). Conversely, the concentration of Fe across manure rates was higher in soil amended with LCM than CCM (Fig. 2d). At the highest manure rate of 10 t ha⁻¹, the concentration of Fe was 38.8% higher in soil amended with LCM than CCM.

Estimates of soil properties influencing trace element pollution and bioaccumulation in celosia

The linear regression was conducted to model the relationship between soil pH, organic C and ECEC against other soil chemical properties, trace element pollution and bioaccumulation in celosia. Due to the adjusted best linear model, the interaction of Na, available P, extractable (Fe, Cu) and soil total Cu contributed to lowering the soil acidity at the rate of 93.80% ($p < 0.001$) (Table 3). The pH of the amended soil was estimated that 1 unit increase in the amount of exchangeable Na and extractable Cu would contribute to 0.11 and 0.13 units in soil pH. The interaction of Al+H, available P, extractable (Mn, Fe, Cu and Zn) was explained at the rate of 96.65% ($p < 0.001$) (Table 3). The soil organic C was estimated that an increase of 1 unit in the amount of extractable Mn and Cu would contribute to 1.70 and 1.18 units of the soil organic C in the amended soil. Interaction of CF-Cd, CF-Cu, CF-Mn and PLI on the ECEC of the soil was at the rate of 92.72% ($p < 0.001$) (Table 3). It was estimated that 1 unit increase in CF-Cd, CF-Cu, CF-Mn would contribute to 2.89, 4.74 and 2.41 units, respectively of the soil's ECEC. Similarly, the interaction of CF-Cd, CF-Cu, CF-Mn as well as PLI with pH of the amended soil was at the rate of 67.77% ($p < 0.001$) (Table 3). It was estimated that 1 unit increase in the amount of PLI would contribute to 2.29 units of the soil pH. The effects of CF-Cu and CF-Mn on the soil organic C was at the rate of 49.10% ($p < 0.001$) (Table 3). It was estimated that 1 unit increase in CF-Mn would contribute to 8.02 units of soil organic C.

The soil properties in respect of pH, ECEC and organic C were also modeled on the assumption that they influence bioaccumulation and transfer of trace elements in tissues of *Celosia argentea*. The interaction of TF-Cu, BCF-Mn, BAC-Mn and TF-Mn was at the rate of 85.51% ($p < 0.001$) (Table 4). It was estimated that 1 unit increase in BAC-Mn would contribute to 0.43 unit of soil pH. The interaction of BAC-Cu, BCF-Mn, BAC-Mn and TF-Mn was at the rate of 82.42% ($p < 0.001$) (Table 4). It was estimated that 1 unit increase in BAC-Cu and BAC-Mn would contribute to 1.09 and 3.96 units of ECEC. The interaction of BCF-Mn, BAC-Mn and TF-Mn was estimated at the rate of 72.45% ($p < 0.001$) as shown in Table 4. It was estimated that 1 unit increase in BCF-Mn and TF-Mn would contribute to 3.80 and 6.93 units, respectively of organic C.

Effects of chicken manure amendments on total and pollution concentration of trace element in soil

The soil total and pollution concentrations of Cd, Cu and Mn were significantly higher in CCM compared to LCM amended soil (Table S1). Generally, chicken manure amendments significantly increased the total concentration and contamination/pollution factor of the amended soil over no amendment (Table 5). Across manure rates, the total concentrations of Cd, Cu and Mn were significantly ($p \leq 0.05$) higher in soil amended with CCM than LCM. At manure rate of 4 t ha⁻¹, the total concentration of Cd in the soil increased by 103.8 % with CCM and by 66.8 % with LCM over no amendment. The total concentration of Cu in the amended soil increased over no amendment by 24.0 % with CCM and by 21.6 % with LCM. Similarly, Mn in the soil increased over no amendment by 23.6 % with CCM and by 19.7 % with LCM. The highest contents of trace elements were recorded in soil that received 10 t ha⁻¹ of the amendments (Table 5). The CF of Cd, Cu, and Mn also showed that trace element pollution of the soil was higher with CCM compared to LCM. However, across amendment rates, only Mn has CF value of less than 1. Further observation on contamination of the soil by Cd, Cu and Mn via indices; TCF, DC, EPI and PLI showed that CCM significantly increased the soil's trace element than LCM (Fig 3a-d). This study revealed that pollution load of chicken manure amended soil increased significantly with manure rates over unamended soil. However, there was no significant difference between 4 and 6 t ha⁻¹ of LCM on the DC of amended soil (Fig 3b). The highest pollution indices of the trace elements were recorded at 10 t ha⁻¹ of the amendments.

Influence of chicken manure amendments on growth and yield characteristics of cockscomb

The growth and yield characteristics of cockscomb grown on soil amended with chicken manure were significantly higher than in unamended soil (Figs. 4 & 5). Except for shoot dry weight, there was no significant difference between the growth characteristics of cockscomb grown on soil amended with CCM and LCM (Table S2). However, significant variation was observed on plant height at 8 t ha⁻¹ with CCM contributing the highest height (Fig. 4a). At 10 t ha⁻¹, the number of leaves and primary branches plant⁻¹ were significantly higher with LCM than CCM (Figs. 4b and 4c). The highest plant height, number of leaves and primary branches recorded with CCM at 8 t ha⁻¹ were not significantly different from that of 6 and 4 t ha⁻¹. On the other hand, the highest growth characteristics with LCM which occurred at 10 t ha⁻¹ were also not different from what was recorded at 8, 6 and 4 t ha⁻¹ of the amendment (Figs. 4a-c).

Shoot fresh biomass of the vegetable grown in soil amended with manure was significantly higher compared with that from the control soil (Fig. 5a). Across amendment rates, there were no differences between the two sources of manure. The highest shoot fresh weight recorded at 8 t ha⁻¹ of the CCM was not different from those at 6 and 10 t ha⁻¹ in soil amended with LCM. The dry shoot weight also showed no difference between the manure sources across rates except at 8 t ha⁻¹ where CCM gave the highest shoot dry weight (Fig. 5b). There were no differences

between the CCM and LCM on the root fresh and dry weights except at 8 t ha⁻¹ of the amendments. The root fresh and dry weights were highest in soil amended with CCM at 8 t ha⁻¹ and decreased afterwards. Conversely in soil amended with LCM, there were no significant differences between root fresh and dry weights across amendment rates (Figs. 5c & d).

Bioaccumulation of Cu and Mn in celosia

Bioaccumulation of Cu and Mn were significantly higher in root and shoot tissues of celosia grown in soil amended with CCM than LCM (Table S3). Across manure rates, BAC of Cu in tissue of celosia was significantly higher with CCM than LCM amendment (Fig. 6a). There was no significant difference in BAC of Cu in celosia from soil with no amendment, 4 and 6 t ha⁻¹ of the CCM. But an initial reduction in BAC of Cu was observed in celosia from soil amended with 4 t ha⁻¹ of the LCM (Fig. 6a). Meanwhile, at 6 through 10 t ha⁻¹, BAC of Cu increased significantly with both amendments although there was no difference between BAC-Cu at 8 and 10 t ha⁻¹ in soil amended with CCM.

The BAC of Mn, was significantly higher across rates with both amendments over unamended soil except at 4 t ha⁻¹ in soil amended with LCM where a significant decrease was recorded (Fig. 6b). The BAC of Mn was significantly higher in soil amended with CCM than LCM at 4 and 6 t ha⁻¹, above which there was no difference between the amendments. Following the highest BAC-Mn recorded at 6 t ha⁻¹, the BAC decreased significantly in tissue of celosia at 8 and 10 t ha⁻¹ in soil amended with CCM. A similar decrease in BAC-Mn was however recorded at 10 t ha⁻¹ in soil amended with LCM (Fig. 6b).

The BCF-Cu was significantly higher across manure rates in soil amended with CCM compared to LCM (Fig. 6c). Celosia grown on soil amended with 4 and 6 t ha⁻¹ of CCM and LCM, respectively were not different significantly in its BCF-Cu from those grown on unamended soil. The LCM significantly reduced BCF-Cu in celosia tissue at 4 t ha⁻¹. The highest BCF of Cu was observed at 8 and 10 t ha⁻¹ of the CCM and LCM, respectively (Fig. 6c). At 6 through 10 t ha⁻¹, the LCM increased BCF of Cu significantly in the vegetable. Meanwhile, there was no difference between BCF-Cu in the celosia at 8 and 10 t ha⁻¹ of soil amended with CCM. The BCF of Mn which increased significantly with rates of amendments was highest at 8 t ha⁻¹ of both the CCM and LCM and decreased afterwards (Fig. 6d).

The two manure sources responded differently on the TF of Cu and Mn in celosia tissues. While the TF-Cu was significantly higher in celosia grown on LCM than CCM amended soil, a reverse scenario was recorded with TF-Mn being higher with CCM than LCM (Table S3). The TF-Cu in tissues of celosia grown in soil amended with 4 t ha⁻¹ of the amendments was not different from that of the control soil (Fig. 6e). At 6 t ha⁻¹ of the amendments, a significant reduction in TF-Cu was recorded for both the CCM and LCM. The amendments at 8 t ha⁻¹ increased TF-Cu compared to the value recorded at lower rate of 6 t ha⁻¹. At 6 and 8 t ha⁻¹, the TF-Cu was significantly higher in soil amended with LCM compared to CCM. However, at 10 t ha⁻¹ of the amendments, there was no difference between the TF-Cu in celosia grown with the two amendments (Fig. 6e). On the TF-Mn, a significant reduction was recorded in the celosia across amendments rates in comparison with unamended soil except at 6 t ha⁻¹ in soil amended with CCM (Fig. 6f). Hence, TF-Mn in celosia from the amended soil decreased significantly with rate over the unamended soil. Transfer factor of Mn was significantly higher in celosia grown in soil amended with CCM than LCM across amendments rates except at 8 t ha⁻¹. Meanwhile the lowest TF-Mn was recorded at 6 and 8 t ha⁻¹ in soil amended with LCM and CCM, respectively.

Concentration and phytoavailability of trace element in celosia tissues

Mean concentration and potential available contents of Cu and Mn in root and shoot tissues of the celosia were significantly higher in CCM than LCM amended soil. Among the trace elements studied, only Cd was below the detection limit of 0.002 mg kg⁻¹ in shoot and root tissues of celosia (Table S4). Concentrations of the trace elements were significantly higher in tissues of celosia grown in chicken manure amended soil compared to unamended (no fertilization) soil. The concentrations of Cu and Mn across rates were also higher in tissues of celosia grown on soil amended with CCM than LCM (Figs. 7a-d). The highest concentration of Cu was recorded in root and shoot tissues at 10 t ha⁻¹ of the amendments (Figs. 7a and 7b). Mean concentration of Mn was highest in the celosia shoot grown in soil amended with CCM and LCM at 6 and 8 t ha⁻¹, respectively (Fig. 7c). In the root however, concentration of Mn was highest at 8 t ha⁻¹ of the amendments (Fig. 7d).

Unlike tissue concentration of the trace element, there were no differences between CCM and LCM across rates except at 8 t ha⁻¹ on the uptake or potentially available contents of Cu and Mn in the celosia tissues (Figs. 7e-h). The highest Cu and Mn were taken up by the root and shoot tissues of the vegetable at 8 t ha⁻¹ with a significant decline at 10 t ha⁻¹ in soil amended with CCM. However, in soil amended with LCM, the highest uptake of Cu and Mn by the root and shoot was comparable at 8 and 10 t ha⁻¹ of the amendment. Only the celosia shoot showed the highest uptake of Cu which was significantly higher than other rates at 10 t ha⁻¹ (Fig. 7e). Meanwhile, across rates except at 8 t ha⁻¹ there were no differences between CCM and LCM on uptake of Cu by the root (Fig. 7f). Uptake of Mn by celosia shoot increased significantly with

rate in soil amended with CCM over unamended soil (Fig. 7g). A similar increase was recorded with rates except at 4 t ha⁻¹ in soil amended with LCM over unamended soil. The pattern of Mn uptake by the root was similar to that of the shoot (Fig. 7h) with both amendments.

Correlations of growth, yield and concentration of trace element in soil and tissues of celosia

Significant positive relationships were found among the growth, yield characteristics, soil and tissue concentrations as well as potentially available contents of the trace element in celosia (Table 6). As the total concentration of trace element in soil amended with chicken manure increased, a proportional increase in growth, yield and bioaccumulation of the trace metals in celosia tissues was recorded.

Correlation coefficients of the selected soil properties, TF, root and shoot uptake of Cu and Mn as well as bioaccumulation of Cu and Mn in tissues of celosia are shown in Table 7. Soil pH significantly and directly influenced ECEC, root-Cu uptake, root-Mn uptake, shoot-Cu uptake, shoot-Mn uptake and bioaccumulation of Cu and Mn in celosia tissues. Meanwhile, the pH was inversely related with TF of the trace elements with a significant negative relationship with TF-Cu ($r = -0.79^{***}$) while the relationship was not significant with TF-Mn. Soil organic carbon was significantly and negatively correlated with ECEC ($r = -0.49^{**}$) and BCF-Mn ($r = -0.50^{**}$) but strongly and positively correlated with TF-Mn ($r = 0.85^{***}$). Although the correlations between organic carbon, uptake and bioaccumulation of Cu and Mn were not significant, an inverse relationship exists amongst them. Effective CEC of the soil was significantly and negatively related with TF-Cu ($r = -0.55^{**}$) and TF-Mn ($r = -0.44^*$). Our observation showed that TF of both Cu and Mn were significantly and negatively correlated with the tissue contents, uptake as well as with bioaccumulation potentials. The contents of trace element in root and shoot tissues were significantly and directly related to the uptake and bioaccumulation potentials of the celosia.

Discussion

The alkaline pH of CCM than LCM was a reflection of the composition of feed the chicken fed on. This is because feeds of egg laying birds are often high in mineral elements such as Ca, Mg, K and P which might have contributed to the calcareous nature of the CCM. Although the organic carbon was higher in CCM than LCM, the lower N content in CCM than LCM could be due to loss of N from volatilization in CCM during air-drying. The higher contents of Fe and Ni in LCM than CCM can be traced to small stones and pebbles on which local chicken picked from the surrounding soils during feeding. Conversely, high concentrations of Mn, Cu, Zn and Cd in CCM can be linked to the residues from feeds and drugs given to chicken raised in cages. Previous studies have traced high content of trace element in poultry manure to feeds and drugs administered on poultry birds (Zhang et al. 2005; Van Zanten et al. 2014; Oguntade et al. 2019). Other trace elements such as Co, Cr and Pb in this study were below the detection limits in both the CCM and LCM.

The increased chemical properties of soil amended with CCM than LCM can be explained by the higher elemental contents of CCM than LCM. Similarly, higher content of Fe in soil amended with LCM over CCM can be attributed to high concentration of Fe in the LCM. Thus, the difference in sources of the chicken manure of different composition must have contributed to variations in chemical properties of the manure amended soil. This is in consonance with the observation of Liu et al. (2021) that farmland soils that received pollutants from different sources varied in its properties including trace elemental contents. In this study, the chicken manure amendments increased nutrients (macro and micro) status of the amended soil with rates compared with unamended soil. Kobierski et al. (2017) have also found increased soil chemical properties in soil fertilized with poultry manure.

Furthermore, the regression analysis of soil pH, organic C and ECEC showed that the nutrient and trace element load in the amended soil increased significantly over the unamended soil. Our observation of the linear regression model revealed that Na, Cu and PLI contributed more to the increased pH of amended soil. Thus, the increased pH of the amended soil impacted; greatly in enhancing PLI of the trace element, moderately on the extractable Cu and to a lesser extent on the exchangeable Na. In this study the PLI modified pH of the amended soil by 2.29 units to minimize contamination factors of Cd, Cu and Mn. In a similar study, Kim et al. (2016) observed integrated pollution index (IPI) as a useful tool for minimizing effects of the differences in trace element contamination apart from monitoring changes in the soil pH. The effect of increased pH of the amended soil on Na⁺ and Cu²⁺ could also be due to sorption of the ionic forms of these metallic elements by soil organic carbon pool. According to Basta et al. (2004) sorption of metallic element by soil organic matter increased with pH because bonding with ionized functional group are preferred with increased pH.

Extractable (Mn, Cu) and CF-Mn were more effective in modifying the organic C content of the soil. This showed that the trace elements competitively sorbs on to the surfaces of the organic C such that Mn was being greatly attracted than Cu. This could be due to oxidation states of + 2 for both Mn²⁺ and Cu²⁺ with which they were bounded to organic ligands as pH of the amended soil increased (Tchounwou 2012; Alloway 2013). Studies have also shown that trace metal cations such as Mn²⁺ and Cu²⁺ because of their properties and higher affinity for organic matter or carbon they tend to sorb on to surfaces of organic ligands (Basta et al., 2004) (Zhang et al., 2015).

The regression also showed that CF-Cd, CF-Cu and CF-Mn play significant role in enhancing ECEC of the amended soil. The adsorption affinities on the ECEC was in the order of CF-Cu > CF-Cd > CF-Mn. Being divalent cationic elements (Cd^{2+} , Cu^{2+} and Mn^{2+}) their valencies and adsorption tendencies could have made their contamination factors significant at the cation exchange site (Liu et al. 2021). Thus, the chemical behaviour of the trace elements could have made them form complexes as in Cd^{2+} , bound to surfaces as in Cu^{2+} or exist in exchangeable form as in Mn^{2+} at the cation exchange site (Alloway, 2013; Rinklebe and Shaheen 2014; Shaheen et al. 2016; Shaheen et al. 2017; Tchounwou et al. 2012). In this study, we can therefore predict toxicity of Cu in the amended soil since it has the most significant effect in enhancing the soils ECEC. This is because studies have identified ECEC as the best indicator for predicting toxicity of Cu in soils (Shaheen et al. 2017; Tchounwou et al. 2012).

On the prediction of which of the bioaccumulation factors were most effective on the selected soil properties, it was observed that BAC-Mn notably decreased in celosia tissue at 6 and 8 t ha^{-1} in soil amended with CCM and LCM, respectively. This showed that the increased soil pH and organic C content at higher manure rate have immobilized Mn^{2+} from bioaccumulating in the shoot tissue due to adsorption in the amended soil (Beiyuan et al. 2017) (Palansooriya et al. 2020). Our observation is in consonance with the assertion that increased soil pH is an essential factor in reducing metal bioavailability in organically amended soil (Lan et al. 2020) (Saengwilai et al. 2020). It was also noted that BAC-Cu and BAC-Mn were more important in enhancing ECEC of the amended soil. This indicated that Cu^{2+} and Mn^{2+} have strong binding potentials for adsorption on the surfaces of negatively charged organic molecules which enhanced the ECEC. Reports have shown that one of the reasons for higher adsorption ability of trace metal on manure amended soil as may be reflecting on ECEC was the presence of larger number of adsorption sites. Or it may be due to the functional groups like phenolic, carboxylic, lactonic, aromatic and amino-groups of the organic particles (Fletcher and Beckett 1987; Choppala et al. 2013; Zhang et al. 2015).

The linear regression model also showed that BCF-Mn and TF-Mn have higher linear correlation with organic C of the amended soil. This observation indicated that organic C largely enhanced mobility of Mn^{2+} from the amended soil via the root to shoot tissues of celosia. This was probably due to presence of dissolved organic C in the amended soil. One of the most important factors determining mobility of trace metal in soils is the content of organic C that may have dissolved from the organic amendments (Kunhikrishnan et al. 2017; Chen et al. 2019).

The higher total concentration of trace element in soil amended with CCM compared to LCM was a reflection of high content of trace element in the former. It has been established that manure from chicken birds under intensive management, fed with concentrates and treated with veterinary drugs have traces of trace metals in their droppings (Zhang et al. 2012) (Oguntade et al. 2019). The CF of Cd, Cu, and Mn also showed that CCM contributed to higher pollution of the amended soil by the trace element than LCM. However, across rates of amendments, only Mn with CF value of less than 1 indicated low pollution. The unamended soil was moderately polluted with Cu having $1 \leq \text{CF} \leq 3$. The amended soil was considerably polluted with Cu because it falls in the CF class of $3 \leq \text{CF} \leq 6$ while it was very highly polluted with Cd due to its $\text{CF} > 6$ (Gong et al. 2008) (Goher et al. 2014). The DC of the amended soil showed that the soil was moderately contaminated with the selected trace elements according to Gong et al. (2008). However, the unamended soil with PLI of more than 2 units was also moderately contaminated. This could be attributed to the inherent properties of the soil which is a function of the soil's geological forming factors (Dung et al. 2013). Although the soil used for this study was moderately contaminated according to Tomlinson et al. (1980), the chicken manure amendments have led to severe contamination of the amended soil. Therefore, soil amendment with chicken manure above 6 t ha^{-1} especially with CCM that gave $\text{PLI} \geq 5$ which showed extreme contamination in this study should be avoided. This is a caution necessary to minimize trace element transfer across the food chain when cultivating vegetables in soil amended with chicken manure. This is because enrichment of soil with organic amendments can contribute to trace metal load in agricultural soils (Su et al. 2014); (Kowalska et al. 2018).

The optimum growth and dry matter yield of celosia at 8 and 10 t ha^{-1} in soil amended with CCM and LCM, respectively could be due to the nutrient and organic C contents of the amendments. The rich nutrient and organic carbon/matter contents of the manure amendments must have modified the physical, chemical, biological and nutritional properties of the soil to increase plant growth (Bolan et al. 2014; Zhang et al. 2015). Although optimum yield was recorded at higher rate, the impact of PLI which enhanced soil pH at higher manure rate reflected trace element contamination of the amended soil. According to (Kalavrouziotis and Koukoulakis 2012), dry matter yield of plant was a reference point in determining extent of soil pollution through CF or PLI. In pot culture such as in this study, it is therefore economical and will be healthier to grow celosia in soil amended with lower rate of chicken manure than higher rate. Since growth and yield recorded at 4 t ha^{-1} of the amendments are comparable to the optimum recorded at 8 and 10 t ha^{-1} , it is imperative to choose lower amendment rate with lowest possible pollution potentials to reduce trace element load in amended soil and possible transfer to the food chain.

Generally, the increased BAC and BCF of Cu and Mn in tissues of celosia grown on soil amended with chicken manure especially at higher rates compared with unamended soil indicated phytoavailability of these trace elements. The initial reduction in BAC-Cu in celosia tissues at 4 t ha^{-1} of the amendments was a manifestation of the chelation-induced effects of the organic amendments (Smolinska 2015) (Huang et al. 2016). Meanwhile, the increase in both BAC-Cu and BCF-Cu at higher rate of 8 and 10 t ha^{-1} could be due to formation of soluble trace metal-

organic complexes (Smolinska 2015) (Huang et al. 2016). Our observation was similar to the outcome of field study on Cd mobilization and phytoavailability in soil amended with composted chicken manure by Li et al. (2016). They found a decreased Cd phytoavailability at lower amendment rates ($< 54 \text{ t ha}^{-1}$) but an increased Cd phytoavailability at higher rates ($> 108 \text{ t ha}^{-1}$) attributed to formation of soluble metal–dissolved organic carbon complexes in the soil. In this study, unlike BAC-Cu, the decreased BAC-Mn in celosia occurred at rates ($> 6 \text{ t ha}^{-1}$) in CCM and rates ($> 8 \text{ t ha}^{-1}$) in LCM amended soils. This was probably due to differences in the chemical behaviour of Cu^{2+} and Mn^{2+} in the amended soil. Or it may be as a result of increased soil pH among other factors (Alloway 2013; Shaheen et al. 2017). It showed that phytoavailability of the trace elements in celosia varied with sources of the chicken manure amendments. Therefore, the dosage rate of manure amendment as well as its quality in terms of the potential dissolved organic carbon should be considered to reduce solubility of trace element in soils for subsequent availability for plant uptake.

The higher TF-Cu in celosia with LCM than CCM especially at 6 and 8 t ha^{-1} showed that LCM promoted mobility of Cu^{2+} via the tissues significantly compared to CCM despite the content of Cu in the CCM. Conversely, higher TF-Mn in celosia grown with CCM than LCM across rates indicated that CCM promoted mobility of Mn^{2+} compared with LCM. This then showed that mobility and phytoextraction potentials of the trace elements is not only dependent on the content but also on the type of trace element and sources of manure amendments. This perhaps could be due to variations in the concentrations of dissolved organic carbon/matter released into the soil solution as pH of the amended soil increased. It was evident in this study as shown by the regression model that organic C contributed most to the decreased TF-Mn in the vegetable. The concentration of organic matter released into the soil solution has been recognized as a key factor that determines trace metal mobility due to its affinity to organic materials at increased pH (Grybos et al. 2007). Meanwhile, the significant reduction in TF of the trace elements at 6 t ha^{-1} of the amendments indicated the optimum rate at which Cu^{2+} and Mn^{2+} were most chelated by these amendments.

Higher concentrations of Cu and Mn in tissues of celosia grown on soil amended with CCM compared with LCM was due to the contents in the amendments. Similarly, higher uptake of the trace elements in tissues of celosia grown on soil amended with CCM compared with LCM was also evidence. The significantly increased concentration and uptake of Cu and Mn in root and shoot tissues of celosia grown on the amended soil across rates compared with unamended soil showed that the trace elements in the amendments were taken up by the vegetable. Since shoot is the edible part of celosia, emphasis was on the trace element taken up by the shoot tissue. The highest uptake of Cu^{2+} and Mn^{2+} at 8 t ha^{-1} of the amendments showed the highest rate at which solubility of these cationic elements was optimum. Above which there was decreased uptake by the vegetable particularly in soil amended with CCM. This further confirmed our earlier observation in this study that at 8 t ha^{-1} , the amendments immobilized the trace elements. The increased soil pH and the soluble portion of organic amendments were perhaps the key factors responsible for the immobilization and hence reduced uptake of Cu^{2+} and Mn^{2+} by the vegetable at 10 t ha^{-1} . Bolan et al. (2003) and Zhang et al. (2015) have reported solubility and phytoavailability of trace metals in soil and crop, respectively as a function of factors like; content of the trace metal in soil, its affinity to organic materials and the amount of dissolved organic matter. Hence, the significant reduction in uptake of trace elements at 10 t ha^{-1} by CCM compared to LCM affirmed the contributory role played by the content of the trace elements which were higher in CCM than LCM.

The relationships among the growth, yield and uptake of the trace elements indicated that significant amount of Cu and Mn taken up by celosia from the amended soil actually contributed to the growth and yield which in turn enhanced uptake. Our observation in this study justified the essentiality of these trace elements in growth and development of celosia. In a previous study by Oguntade et al. (2019), a significant correlation was reported between the growth, yield and uptake of Cu and Mn by Jute mallow (*Corchorus olitorius*), a similar leafy vegetable. Hanč et al. (2008) had also reported that close relationship exists between Cu taken up by oat and its biomass yield. The well correlated relationships found between concentration of trace elements in soil and in root-shoot tissues as well as uptake could be an indicator of phytoavailability of these trace elements.

However, the inverse relationship between soil pH and the TF showed that increased pH of amended soil mitigate TF of the trace elements in tissues of celosia. Unlike in unamended soil, high pH of the amended soil must have contributed to adsorption of cationic trace elements (Cu^{2+} and Mn^{2+}) onto the surface of organic particles thereby restricting phytoavailability and hence translocation which resulted in reduced uptake. Studies have shown that plant uptake of trace element ions by a growing vegetables was restricted at high soil pH due to adsorption on clay minerals surfaces (Kim et al. 2016)(Liu et al. 2021). The organic particles of the amendments and clay minerals have similar colloidal negatively-charged surfaces which attracts cationic elements.

The negative relationships between Organic C, ECEC and BCF-Mn showed that the increased organic C content of the amended soil reduces potential ECEC such that proportion of the trace elements at the soil exchange site decreased significantly. Similarly, BCF-Mn decreased significantly which indicated that the amendments restrain mobility of Mn from the soil via root of celosia. Animal wastes such as cow dung, pig manure and poultry manure used as soil amendments have been noted to suitably reduce mobility of potentially toxic elements in soils

(Bolan et al. 2003)(Palansooriya et al. 2020). Meanwhile, the root to shoot translocation of Mn was enhanced by the organic C as signified by the positive relationships that exist between the organic C and TF-Mn in this study.

The significant negative relationships among ECEC, TF-Cu and TF-Mn could be due to influence of soil-plant barriers towards reducing translocation of the trace elements into the edible shoot of the vegetable. According to Basta et al. (2005) soil-plant barriers hinders translocation of trace metal via the food chain either by chemical processes that limit solubility in soils (soil barrier) or by senescence resulting from phytotoxicity in plants (plant barrier). They opined that translocation of trace elements such as Au, Ag, Hg, Si, Ti, V and Zr that were highly insoluble or strongly adsorbed to soil or plant roots are limited by soil barrier. Whereas trace elements such as As, Cr, Cu, F, Mn, Ni and Zn which often cause phytotoxicity in plants before accumulation levels in edible parts of plants considered harmful to man, are limited by plant barrier. Therefore, the positive relationship that exists between ECEC, concentration and uptake in the root and shoot as well as on bioaccumulation of Cu and Mn in celosia tissues showed that these attributes were enhanced at the soil exchange site.

The inverse relationship found among TF of Cu and Mn with the tissue concentrations and uptake as well as phytoextraction efficiency of celosia showed that root-shoot translocation of the trace elements was restricted. This means that availability of the trace elements in the edible shoot of celosia decreased significantly. However, a significant positive relationship amongst the concentrations, uptake and phytoextraction potentials of Cu and Mn by celosia implies that the higher the trace metal loads of soil, the higher the potential of uptake and bioaccumulation in celosia tissues. Although mobility of Cu and Mn were restricted by root and shoot, it is evident that celosia tissue was effective in enhancing soil-plant movement of Cu and Mn in this study.

Conclusion

Soil amendment with chicken manure from different sources enhanced soil pH, organic C and ECEC to modify trace element pollution of amended soil. Amendment with CCM contributed significant amount of trace elements (Cu, Cd and Mn) to soil pollution indices compared to LCM. Contamination factor and PLI contributed most to trace element pollution of the amended soil. Trace element pollution of amended soil increased with chicken manure rates over unamended soil. Soil-plant mobility and availability of trace element were mitigated by manure amendments. Trace element transfer from soil via the root to shoot tissues depends not only on total concentration in soil but also on the type of element and sources of chicken manure involved. Phytoextraction potentials of Cu by celosia were higher compared to Mn. Soil amendment with chicken manures above 6 t ha⁻¹ is not encouraged to avoid buildup of trace element in soils and its subsequent transfer to food crops.

Declarations

Ethics approval and consent to participate: Not applicable.

Consent for publication: Not applicable.

Funding information: Not applicable

Availability of data and materials: All datasets generated and used for the current study are available from the corresponding author on reasonable request.

Competing interests: The authors declare no competing interests.

Authors contributions: Conceptualization and methodology was done by Oladele Abdulahi Oguntade; Formal analysis and investigation were done by Oladele Abdulahi Oguntade, Nosiru Monday Yisa and Solomon Oladimeji Olagunju; Writing - original draft preparation was by Oladele Abdulahi Oguntade; Writing - review and editing were done by all co-authors; Funding acquisition involved all co-authors; Resources were made available by Oladele Abdulahi Oguntade, Olufemi Sunday Sosanya, Abiodun Oladipupo Joda, Kayode Matthew Adewusi and Richard Oluseyi Olayiwola while supervision was done by Oladele Abdulahi Oguntade and Nosiru Monday Yisa.

Acknowledgements: The authors are grateful to Prof. F. O. Olasantan who painstakingly edited the manuscript.

References

1. Adeli A, Sistani KR, Tewolde H, Rowe DE (2007) Broiler litter application effects on selected trace elements under conventional and no-till systems. *Soil Science* 172(5):349–365. <https://doi.org/10.1097/ss.0b013e318032ab7d>
2. Alam MGM, Snow ET, Tanaka A (2003) Arsenic and heavy metal contamination of rice, pulses and vegetables grown in Samta village, Bangladesh. *Arsenic Exposure and Health Effects* 308:103–114. <https://doi.org/10.1016/B978-044451441-7/50009-9>

3. Alloway BJ (2013) Sources of Heavy Metals and Metalloids in Soils. in: Heavy Metals in Soils: Trace Metals and Metalloids in Soils and their Bioavailability, (Ed.) B.J. Alloway, Springer Netherlands. Dordrecht, pp. 11–50.
4. Amin H, Arain BA, Jahangir TM, Sadiq M, Amin F (2018) Accumulation and distribution of lead (Pb) in plant tissues of guar (*Cyamopsis tetragonoloba* L.) and sesame (*Sesamum indicum* L.): profitable phytoremediation with biofuel crops. *Geology, Ecology and Landscapes* 9508:1–10. <https://doi.org/10.1080/24749508.2018.1452464>
5. Anderson JM, Ingram JSI (1993) Soil organic matter and organic carbon. In 'Tropical soil biology and fertility: a handbook of method of analysis'. Anderson JM Ingram JSI (Eds.), CAB International: Wallingford, UK. pp. 62–70.
6. Antonious GF, Kochhar TS, Coolong T (2012) Yield, quality, and concentration of seven heavy metals in cabbage and broccoli grown in sewage sludge and chicken manure amended soil. *Journal of Environmental Science and Health - Part A Toxic/Hazardous Substances and Environmental Engineering* 47(13):1955–1965. <https://doi.org/10.1080/03601234.2012.676509>
7. Baker AJM (1981) Accumulators and Excluders - Strategies in the Response of Plants to Heavy Metals. *Journal of Plant Nutrition* 3(1–4):643–654. <https://doi.org/10.1080/01904168109362867>
8. Bandow N, Simon FG (2016) Significance of cadmium from artists' paints to agricultural soil and the food chain. *Environmental Sciences Europe* 28:12. <https://doi.org/10.1186/s12302-016-0077-6>.
9. Basta NT, Ryan JA, Chaney RL (2005) Trace Element Chemistry in Residual-Treated Soil: Key Concepts and Metal Bioavailability. *J Environ Qual* 34:49–63.
10. Beiyuan J, Awad YM, Beckers F, Tsang DC, Ok YS, Rinklebe J (2017) Mobility and phytoavailability of As and Pb in a contaminated soil using pine sawdust biochar under systematic change of redox conditions. *Chemosphere* 178:110–118.
11. Bolan N, Adriano D, Mani S, Khan A (2003) Adsorption, complexation, and phytoavailability of copper as influenced by organic manure. *Environ Toxicol Chem* 22(2):450–456
12. Bolan N, Kunhikrishnan A, Thangarajan R, Kumpiene J, Park J, Makino T, Kirkham MB, Scheckel K, (2014) Remediation of heavy metal(loid)s contaminated soils—to mobilize or to immobilize? *J Hazard Mater* 266:141–166.
13. Bouyoucos GH (1962) Hydrometer method for making particle size analysis of soils. *Agronomy Journal* 54:464–465. <https://doi.org/10.2134/agronj1962.00021962005400050028x>.
14. Bremner JM, Mulvaney CS (1982) Nitrogen-Total. In: Methods of soil analysis. Part 2. Chemical and microbiological properties, Page AL, Miller RH, Keeney DR, Eds., American Society of Agronomy, Soil Science Society of America, Madison, Wisconsin, 595-624.
15. Bu-Olayan AH, Thomas BT (2009) Translocation and bioaccumulation of trace metals in desert plants of Kuwait Governorates. *Research Journal of Environmental Sciences* 3(5):581-587 <https://doi.org/10.3923/rjes.2009.581.587>
16. Cabrera F, Clemente L, Díaz Barrientos E, López R, Murillo JM (1999) Heavy metal pollution of soils affected by the Guadamar toxic flood. *Science of the Total Environment* 242(1–3):117–129. [https://doi.org/10.1016/S0048-9697\(99\)00379-4](https://doi.org/10.1016/S0048-9697(99)00379-4)
17. Chen H, Yang X, Gielen G, Mandal S, Xu S, Guo J, Shaheen SM, Rinklebe J, Che L, Wang H (2019) Effect of biochars on the bioavailability of cadmium and di-(2-ethylhexyl) phthalate to *Brassica chinensis* L. in contaminated soils. *Sci Total Environ* 678:43–52.
18. Choppala G, Bolan N, Kunhikrishnan A, Skinner W, Seshadri B (2013) Concomitant reduction and immobilization of chromium in relation to its bioavailability in soils. *Environ Sci Pollut Res* 20:1–10
19. Dung TTT, Cappuyns V, Swennen R, Phung NK (2013) From geochemical background determination to pollution assessment of heavy metals in sediments and soils. *Reviews in Environmental Science and Biotechnology* 12(4):335–353. <https://doi.org/10.1007/s11157-013-9315-1>
20. Eugenio NR, Naidu R, Colombo CM (2020) Global approaches to assessing, monitoring, mapping, and remedying soil pollution. *Environmental Monitoring and Assessment* 192(9):601. <https://doi.org/10.1007/s10661-020-08537-2>.
21. Fiori CS, Rodrigues AP, Santelli RE, Cordeiro RC, Carvalho RG, Araujo PC, Castilhos ZC, Bidone ED (2013) Ecological risk index for aquatic pollution control: a case study of coastal water bodies from the Rio de Janeiro State, southeastern Brazil. *Geochimica Brasiliensis* 27(1):24-36. <https://doi.org/10.21715/gb.v27i1.386>.
22. Fletcher P, Beckett PHT (1987) The chemistry of heavy-metals in digested sewage-sludge-II. Heavy-metal complexation with soluble organic matter. *Water Res* 21:1163–1172
23. Goher ME, Farhat HI, Abdo MH, Salem SG (2014) Metal pollution assessment in the surface sediment of Lake Nasser, Egypt. *Egyptian Journal of Aquatic Research* 40(3):213–224. <https://doi.org/10.1016/j.ejar.2014.09.004>
24. Gong Q, Deng J, Xiang Y, Wang Q, Yang L (2008) Calculating pollution indices by heavy metals in ecological geochemistry assessment and a case study in parks of Beijing. *Journal of China University of Geosciences* 19(3):230–241. [https://doi.org/10.1016/S1002-0705\(08\)60042-4](https://doi.org/10.1016/S1002-0705(08)60042-4).

25. Grybos M, Davranche M, Gruau G, Petitjean P (2007) Is trace metal release in wetland soils controlled by organic matter mobility or Fe-oxyhydroxides reduction? *Journal of Colloid and Interface Science* 314:490–501. <https://doi.org/10.1016/j.jcis.2007.04.062>
26. Håkanson L (1980) An ecological risk index for aquatic pollution control. A sedimentological approach. *Water Research* 14(8):975–1001. [https://doi.org/10.1016/0043-1354\(80\)90143-8](https://doi.org/10.1016/0043-1354(80)90143-8)
27. Hanč A, Tlustoš P, Száková J, Habart J, Gondek K (2008) Direct and subsequent effect of compost and poultry manure on the bioavailability of cadmium and copper and their uptake by oat biomass. *Plant, Soil and Environment* 54(7):271–278.
28. Hough RL, Young SD, Crout NMJ (2003) Modelling of Cd, Cu, Ni, Pb and Zn uptake, by winter wheat and forage maize, from a sewage disposal farm. *Soil Use and Management* 19(1):19–27. <https://doi.org/10.1079/sum2002157>
29. Hseu Z, Chen Z, Tsai C, Tsui Cheng S, Liu C, Lin H (2002). Digestion methods for total heavy metals in sediments and soils. *Water Air Soil Pollut* 141:189–205
30. Huang M, Zhu Y, Li Z, Huang B, Luo N, Liu C, Zeng G (2016) Compost as a Soil Amendment to Remediate Heavy Metal-Contaminated Agricultural Soil: Mechanisms, Efficacy, Problems, and Strategies. *Water Air Soil Pollut* 227:359. <https://doi.org/10.1007/s11270-016-3068-8>
31. Islam MS, Ahmed MK, Al-Mamun MH, Masunaga S (2015) Potential ecological risk of hazardous elements in different land-use urban soils of Bangladesh. *Sci Total Environ* 512–513:94–102. <http://dx.doi.org/10.1016/j.scitotenv.2014.12.100>.
32. Jamali MK, Kazi TG, Arain MB, Afridi HI, Jalbani N, Kandhro GA, Shah AQ, Baig JA (2009) Heavy metal accumulation in different varieties of wheat (*Triticum aestivum* L.) grown in soil amended with domestic sewage sludge. *Journal of Hazardous Materials* 164(2–3):1386–1391. <https://doi.org/10.1016/j.jhazmat.2008.09.056>
33. Jorfi S, Maleki R, Jaafarzadeh N, Ahmadi M (2017) Pollution load index for heavy metals in Mian-Ab plain soil, Khuzestan, Iran. *Data in Brief* 15:584–590. <https://doi.org/10.1016/j.dib.2017.10.017>
34. Kalavrouziotis IK, Koukoulakis PH (2012) Soil pollution under the effect of treated municipal wastewater. *Environmental Monitoring and Assessment* 184(10):6297–6305. <https://doi.org/10.1007/s10661-011-2420-0>
35. Khan MN, Mobin M, Abbas ZK, Alamri SA (2017) Fertilizers and their contaminants in soils, surface and groundwater. In *Encyclopedia of the Anthropocene* 1–5: Elsevier Inc. <https://doi.org/10.1016/B978-0-12-809665-9.09888-8>
36. Kim M-S, Min H, Lee S, Kim J (2016) The Effects of Various Amendments on Trace Element Stabilization in Acidic, Neutral, and Alkali Soil with Similar Pollution Index. *Plos One* 11(11):1-12. <https://doi.org/10.1371/journal.pone.0166335>
37. Kobierski M, Bartkowiak A, Lemanowicz J, Piekarczyk M (2017) Impact of poultry manure fertilization on chemical and biochemical properties of soils. *Plant, Soil and Environment* 63(12):558–563. <https://doi.org/10.17221/668/2017-PSE>
38. Kowalska JB, Mazurek R, Gąsiorek M, Zaleski T (2018) Pollution indices as useful tools for the comprehensive evaluation of the degree of soil contamination—A review. *Environmental Geochemistry and Health* 40(6):2395–2420. <https://doi.org/10.1007/s10653-018-0106-z>
39. Kunhikrishnan A, Choppala G, Seshadri B, Wijesekara H, Bolan NS, Mbene K, Kim W-I (2017) Impact of wastewater derived dissolved organic carbon on reduction, mobility, and bioavailability of As (V) and Cr (VI) in contaminated soils. *J. Environ. Manag.* 186:183–191.
40. Lan MM, Liu C, Liu SJ, Qiu RL, Tang YT (2020) Phytostabilization of Cd and Pb in highly polluted farmland soils using ramie and amendments. *International Journal of Environmental Research and Public Health* 17(5):1-12. <https://doi.org/10.3390/ijerph17051661>
41. Li, M, Mohamed I, Raleve D, Chen W, Huang Q (2016) Field evaluation of intensive compost application on Cd fractionation and phytoavailability in a mining-contaminated soil. *Environ. Geochem. Health* 38 (5):1193–1201.
42. Liu W, Yang X, Duan L, Naidu R, Yan K, Liu Y, Wang X, Gao Y, Chen Y (2021) Variability in plant trace element uptake across different crops, soil contamination levels and soil properties in the Xinjiang Uygur Autonomous Region of northwest China. *Scientific Reports* 11(1):1–13. <https://doi.org/10.1038/s41598-021-81764-w>
43. Luo L, Ma Y, Zhang S, Wei D, Zhu YG (2009) An inventory of trace element inputs to agricultural soils in China. *Journal of Environmental Management* 90(8):2524–2530. <https://doi.org/10.1016/j.jenvman.2009.01.011>
44. McLean EO, Dumford SWF, Coronel SW (1982) A comparison of several methods of determining lime requirements of soil. *Soil Science Society of America Proceedings* 30:26-30.
45. Mortola N, Romaniuk R, Cosentino V, Eiza M, Carfagno P, Rizzo P, Bres P, Riera N, Roba M, Butti M, Sainz D, Brutti L (2019) Potential Use of a Poultry Manure Digestate as a Biofertiliser: Evaluation of Soil Properties and *Lactuca sativa* Growth. *Pedosphere* 29(1):60–69. [https://doi.org/10.1016/S1002-0160\(18\)60057-8](https://doi.org/10.1016/S1002-0160(18)60057-8)
46. Nelson DW, Sommers LE (1996) Total carbon, organic carbon, and organic matter. In 'Methods of soil analysis. Part 3'. Sparke DL (Ed.). Chemical methods SSSA book series no: Madison, ASA and SSSA 5. pp. 961-1010.
47. Nicholson FA, Chambers BJ, Williams JR, Unwin RJ (1999) Heavy metal contents of livestock feeds and animal manures in England and Wales. *Bioresource Technology* 70(1):23–31. [https://doi.org/10.1016/S0960-8524\(99\)00017-6](https://doi.org/10.1016/S0960-8524(99)00017-6)

48. Oguntade OA, Adetunji MT, Azeez JO (2015) Uptake of manganese, iron, copper, zinc and chromium by *Amaranthus cruentus* L. irrigated with untreated dye industrial effluent in low land field. *Journal of Environmental Chemical Engineering* 3:2875–2881. <http://dx.doi.org/10.1016/j.jece.2015.10.022>.
49. Oguntade OA, Odusanya OA, Olagunju SO, Oduntan OB, Adewusi KM, Adegoke AT (2017) Residual effect of composted poultry manure on yield and bioaccumulation of Iron , Zinc , Lead and Cadmium in tissues of Common Cockscorn (*Celosia argentea* L .) grown on soils from waste dumpsite and farmland. *African Journal of Agriculture Technology and Environment* 6(1):79–88.
50. Oguntade OA, Odusanya OA, Olagunju SO, Adewusi KM, Adegoke AT (2018). Residual effect of composted kitchen waste and poultry manure soil amendments on yield and concentrations of copper, iron, manganese and zinc in leaf tissue of Jute mallow (*Corchorus Olitorius* Linn). *Ife Journal of Agriculture* 30(2):65–76.
51. Oguntade OA, Olagbenro TS, Odusanya OA, Olagunju SO, Adewusi KM, Adegoke AT (2019) Assessment of composted kitchen waste and poultry manure amendments on growth, yield and heavy metal uptake by Jute mallow *Corchorus olitorius* Linn. *International Journal of Recycling of Organic Waste in Agriculture* 8(2):187–195. <https://doi.org/10.1007/s40093-018-0232-8>
52. Oguntade OA, Adegbuyi AA, Nassir AL, Olagunju SO, Salami WA, Adewale RO (2020) Geoassessment of heavy metals in rural and urban floodplain soils: health implications for consumers of *Celosia argentea* and *Corchorus olitorius* vegetables in Sagamu, Nigeria. *Environmental Monitoring and Assessment* 192(3):164. <https://doi.org/10.1007/s10661-020-8077-9>
53. Palansooriya KN, Shaheen SM, Chen SS, Tsang DCW, Hashimoto Y, Hou D, Bolan NS, Rinklebe J, Ok YS (2020) Soil amendments for immobilization of potentially toxic elements in contaminated soils: A critical review. *Environment International* 134: 105046. <https://doi.org/10.1016/j.envint.2019.105046>
54. Payne RW, Harding SA, Murray DA, Soutar DM, Baird DB, Glaser AI, Channing IC, Welham SJ, Gilmour AR, Thompson R, Webster R (2009) *GenStat for Windows* (12 edition) Introduction.- VSN International, Hemel Hempstead, UK.
55. Rinklebe J, Shaheen SM (2014) Assessing the mobilization of cadmium, lead, and nickel using a seven-step sequential extraction technique in contaminated floodplain soil profiles along the central Elbe River. Germany. *Water, Air & Soil Pollution* 225 (8):2039.
56. Salem HM, Eweida EA, Farag A (2000) Heavy metals in drinking water and their environmental impact on human health. *ICEHM*, 542–556.
57. Saengwilai P, Meeinkuirt W, Phusantisampan T, Pichtel J (2020) Immobilization of cadmium in contaminated soil using organic amendments and its effects on rice growth performance. *Exposure and Health* 12:295–306.
58. Sastre J, Sahuquillo A, Vidal M, Rauret G. (2002) Determination of Cd, Cu, Pb and Zn in environmental samples microwave-assisted total digestion versus aqua regia and nitric acid extraction. *Anal Chim Acta* 462:59–72.
59. Shaheen SM, Rinklebe J, Frohne T, White JR, DeLaune RD (2016) Redox effects on release kinetics of arsenic, cadmium, cobalt, and vanadium in Wax Lake Deltaic freshwater marsh soils. *Chemosphere* 150:740–748.
60. Shaheen SM, Shams MS, Khalifa MR, Mohamed A, Rinklebe J (2017) Various soil amendments and environmental wastes affect the (im)mobilization and phytoavailability of potentially toxic elements in a sewage effluent irrigated sandy soil. *Ecotoxicol Environ Saf* 142:375–387.
61. Shakoor MB, Niazi NK, Bibi I, Murtaza G, Kunhikrishnan A, Seshadri B, Shahid M, Ali S, Bolan NS, Ok YS, Abid M, Ali F (2016) Remediation of arsenic-contaminated water using agricultural wastes as biosorbents. *Critical Reviews in Environmental Science and Technology* 46(5):467–499. <https://doi.org/10.1080/10643389.2015.1109910>
62. Shomar B, Kalavrouziotis IK (2013) Soil Pollution Indices Under the Effect of Sludge. *Water Air Soil Pollut* 224:1436. <https://doi.org/10.1007/s11270-013-1436-1>
63. Smolinska, B (2015) Green waste compost as an amendment during induced phytoextraction of mercury-contaminated soil. *Environmental Science and Pollution Research* 22(5):3528–3537.
64. Su C, Jiang L, Zhang W (2014) A review on heavy metal contamination in the soil worldwide: Situation , impact and remediation techniques. *Environmental Skeptics and Critics* 3(2):24-38
65. Tchounwou PB, Yedjou CG, Patlolla AK, Sutton DJ (2012) Heavy metal toxicity and the environment. In: *Toxicology, Environmental (Ed.), Molecular, Clinical and Environmental Toxicology: Volume 3*. Springer Basel. Basel, A. Luch, pp. 133–164.
66. Tomlinson DC, Wilson JG, Harris CR, Jeffrey DW (1980) Problems in the assessment of heavy metals levels in estuaries and the formation of pollution index. *Helgolander Wissenschaft Meeresuntersuchungen* 33:566–569.
67. Turekian KK, Wedepohl KH (1961) Distribution of the elements in some major units of the Earth's crust. *Geological Society of American Bulletin* 72(2):175–192. [https://doi.org/10.1130/0016-7606\(1961\)72\[175:DOTAIS\]2.0.CO;2](https://doi.org/10.1130/0016-7606(1961)72[175:DOTAIS]2.0.CO;2).
68. Udo EJ, Ibis TO, Ogunwale JA, Ano AO, Esu IE (2009) *Manual of Soil, Plant and Water Analysis*. Lagos: Sibon Books Ltd 183 pp.

69. Ugulu I, Ahmad K, Khan ZI, Munir M, Wajid K, Bashir H (2021) Effects of organic and chemical fertilizers on the growth, heavy metal/metalloid accumulation, and human health risk of wheat (*Triticum aestivum* L.). *Environmental Science and Pollution Research* 28(10):12533–12545. <https://doi.org/10.1007/s11356-020-11271-4>
70. Van Zanten HHE, Mollenhorst H, De Vries JW, Van Middelaar CE, Van Kernebeek HRJ, De Boer IJM (2014) Assessing environmental consequences of using co-products in animal feed. *International Journal of Life Cycle Assessment* 19(1):79–88. <https://doi.org/10.1007/s11367-013-0633-x>
71. Wajid K, Ahmad K, Iqbal Z, Muhammad K (2020) Pattern of trace metal uptake in Pearl millet as a result of application of organic and synthetic fertilizers. *International Journal of Environmental Research*. 15(1):33-44. <https://doi.org/10.1007/s41742-020-00287-w>
72. Walkley A, Black IA (1934) An examination of the degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. In *Soil Science* 37(1):29–38. <https://doi.org/10.1097/00010694-193401000-00003>
73. Yoon J, Cao X, Zhou Q, Ma LQ (2006) Accumulation of Pb, Cu, and Zn in native plants growing on a contaminated Florida site. *Science of the Total Environment* 368(2–3):456–464. <https://doi.org/10.1016/j.scitotenv.2006.01.016>
74. Zhang SQ, Zhang FD, Liu XM, Wang YJ, Zou SW, He XS (2005) Determination and analysis on main harmful composition in excrement of scale livestock and poultry feedlots. *Plant Nutr Fert Sci* 11:822–829.
75. Zhang F, Li Y, Yang M, Li W (2012) Content of heavy metals in animal feeds and manures from farms of different scales in Northeast China. *International Journal of Environmental Research and Public Health* 9(8):2658–2668. <https://doi.org/10.3390/ijerph9082658>.
76. Zhang C, Clark GJ, Patti AF, Bolan N, Cheng M, Sale PWG, Tang C (2015) Contrasting effects of organic amendments on phytoextraction of heavy metals in a contaminated sediment. *Plant and Soil* 397(1–2):331–345. <https://doi.org/10.1007/s11104-015-2615-1>

Tables

Table 1 Physicochemical properties of the experimental soil and chicken manure amendments

Table 2 Effects of chicken manure amendment on chemical properties of soil

Properties	Soil		Chicken manure		
		unit	Conventional	Local	unit
pH	^a 5.73		^a 9.86	^a 7.47	
Calcium	^c 7.58	cmol kg ⁻¹	^c 15.00	^c 6.10	g kg ⁻¹
Magnesium	^c 3.60	cmol kg ⁻¹	^c 23.40	^c 8.70	g kg ⁻¹
Potassium	^c 0.22	cmol kg ⁻¹	^c 7.10	^c 6.70	g kg ⁻¹
Sodium	^c 0.35	cmol kg ⁻¹	^c 2.10	^c 4.00	g kg ⁻¹
Exch. Acidity	^b 0.11	cmol kg ⁻¹	-	-	
ECEC	^c 11.86	cmol kg ⁻¹	-	-	
Base saturation	^c 99.07	%	-	-	
Total Org. C.	^d 21.50	g kg ⁻¹	^f 163.10	^f 141.90	g kg ⁻¹
Total N	^e 1.73	g kg ⁻¹	^e 39.80	^e 41.70	g kg ⁻¹
C/N ratio	-		4.10	3.40	
Phosphorus	^f 8.38 ^f	mg kg ⁻¹	^f 4.90	^f 2.00	mg kg ⁻¹
Manganese	^g 39.65	mg kg ⁻¹	^{c,h} 785.00	^{c,h} 166.00	mg kg ⁻¹
Iron	^{g,h} 82.90	mg kg ⁻¹	^{c,h} 738.00	^{c,h} 5300.00	mg kg ⁻¹
Copper	^{g,h} 1.19	mg kg ⁻¹	^{c,h} 266.40	^{c,h} 56.10	mg kg ⁻¹
Zinc	^{g,h} 7.51	mg kg ⁻¹	^{c,h} 624.20	^{c,h} 554.60	mg kg ⁻¹
Cobalt	^{c,h} BDL	mg kg ⁻¹	^{c,h} BDL	^{c,h} BDL	mg kg ⁻¹
Nickel	^g 9.91	mg kg ⁻¹	^{c,h} 3.30	^{c,h} 4.75	mg kg ⁻¹
Chromium	^{c,h} BDL	mg kg ⁻¹	^{c,h} BDL	^{c,h} BDL	mg kg ⁻¹
Cadmium	^g 7.31	mg kg ⁻¹	^{c,h} 18.10	^{c,h} 17.50	mg kg ⁻¹
Lead	^{c,h} BDL	mg kg ⁻¹	^{c,h} BDL	^{c,h} BDL	mg kg ⁻¹
Sand	ⁱ 866.00	g kg ⁻¹	-	-	
Silt	ⁱ 54.00	g kg ⁻¹	-	-	
Clay	ⁱ 80.00	g kg ⁻¹	-	-	
Textural class	Loamy sand				
BDL = below detection limits of 0.05, 0.003 and 0.04 mg kg ⁻¹ for Co, Cr and Pb, respectively. ^a McLean et al. (1982); ^b Anderson and Ingram (1993); ^c Udo et al. (2009); ^d Walkley and Black (1934); ^e Bremner and Mulvaney 1982; ^f Nelson and Sommers 1996; ^g Hseu et al., 2002; ^h Sastre et al., 2002; ⁱ Bouyoucos 1962					

Sources of Variation	pH	Total N	Org. C	Avail P	Al+H	Ca	K	Mg	Na	ECEC	Extractable				
											Cu	Fe	Mn	Zn	
		(g kg ⁻¹)		(mg kg ⁻¹)	(cmol kg ⁻¹)						(mg kg ⁻¹)				
Manure (M)															
Conventional	6.08	0.75	6.30	12.88	0.13	6.99	0.18	3.55	0.70	11.54	1.56	3.01	18.91	1.26	
Local	5.93	0.56	4.15	10.82	0.14	6.31	0.14	3.43	0.81	10.82	1.15	3.60	14.54	0.93	
(sig.)	***	***	***	***	**	***	***	ns	***	***	***	***	***	***	
LSD	0.02	0.07	0.13	0.08	0.01	0.07	0.01	0.13	0.01	0.17	0.03	0.03	0.18	0.03	
Rates (R)															
0 (control)	5.77	0.65	8.07	7.09	0.11	5.58	0.10	3.08	0.31	9.16	0.64	1.67	9.77	0.40	
4 (t ha ⁻¹)	6.00	0.80	5.48	9.97	0.13	6.12	0.12	3.32	0.81	10.51	1.17	3.33	14.19	0.99	
6 (t ha ⁻¹)	6.12	0.55	4.75	12.64	0.13	6.48	0.15	3.53	0.92	11.20	1.42	3.43	16.90	1.10	
8 (t ha ⁻¹)	6.10	0.60	3.62	14.16	0.14	6.79	0.18	3.62	0.94	11.66	1.64	3.85	19.96	1.37	
10 (t ha ⁻¹)	6.02	0.68	4.22	15.39	0.14	8.28	0.24	3.91	0.80	13.37	1.90	4.25	22.81	1.60	
(sig.)	***	**	***	***	***	***	***	***	***	***	***	***	***	***	
LSD	0.03	0.11	0.20	0.13	0.01	0.10	0.01	0.21	0.02	0.27	0.05	0.05	0.28	0.04	
Interaction															
M x R	***	**	***	***	ns	***	**	ns	***	***	***	***	***	***	
LSD	0.04	0.16	0.28	0.19	0.01	0.15	0.02	0.30	0.02	0.38	0.06	0.07	0.40	0.06	
***, ** = significant at $p\leq 0.001, 0.01$, respectively; ns = not significant															

Table 3 Linear regression model of soil pH, Org.C and ECEC influencing soil elemental composition and pollution indices

Soil properties	Model building	R-Sq (%)	Final model equation
pH	X1:Na	93.80	$= 1.0779+0.10678 X1-0.0547 X2-0.07369 X3+0.1301 X4-0.1863 X5$
	X2:Avail.P		
	X3:Extract. Fe		
	X4:Extract. Cu		
	X5:Soil T.Cu		
Org.C	X1:Al+H	96.65	$= 2.599-0.456 X1-2.659 X2+1.699 X3-0.924 X4+1.183 X5-0.441 X6$
	X2:Avail.P		
	X3:Extract. Mn		
	X4:Extract.Fe		
	X5:Extract. Cu		
	X6:Extract.Zn		
ECEC	X1:CF-Cd	92.72	$= -0.630+2.885 X1+4.74 X2+2.412 X3-8.41 X4$
	X2:CF-Cu		
	X3:CF-Mn		
	X4:PLI		
pH	X1:CF-Cd	67.77	$= 1.0666-0.734 X1-1.197 X2-0.429 X3+2.294 X4$
	X2:CF-Cu		
	X3:CF-Mn		
	X4:PLI		
Org.C	X1:CF-Cu	49.10	$= 3.737-10.76 X1+8.02 X2$
	X2:CF-Mn		
ECEC = effective cation exchange capacity			

Table 4 Linear regression model of soil pH, Org.C and ECEC influencing bio-concentration and transfer factor of trace element

Soil properties	Model building	R-Sq (%)	Final model equation
pH	X1:TF-Cu	85.51	= 1.422-0.0722 X1-0.351 X2+0.427 X3-0.421 X4
	X2:BCF-Mn		
	X3:BAC-Mn		
	X4:TF-Mn		
ECEC	X1:BAC-Cu	82.42	= 4.551+1.094 X1-4.157 X2+3.955 X3-4.442 X4
	X2:BCF-Mn		
	X3:BAC-Mn		
	X4:TF-Mn		
Org.C	X1:BCF-Mn	72.45	= -6.03+3.80 X1-3.70 X2+6.93 X3
	X2:BAC-Mn		
	X3:TF-Mn		
ECEC = effective cation exchange capacity			

Table 5 Mean total concentration and contamination factors of Cadmium, Copper and Manganese in soil amended with chicken manure

Manure Rate	Total soil Cd		Total soil Cu		Total soil Mn		CF-Cd		CF-Cu		CF-Mn	
	mg kg ⁻¹											
	CCM	LCM	CCM	LCM	CCM	LCM	CCM	LCM	CCM	LCM	CCM	LCM
0 (control)	1.873 ^h	1.877 ^h	10.08 ^g	10.03 ^g	249.4 ^g	250.9 ^g	53.5 ^h	53.6 ^h	2.508 ^g	2.51 ^g	0.227 ^g	0.228 ^g
4 (t ha ⁻¹)	3.817 ^f	3.130 ^g	12.50 ^e	12.20 ^f	308.2 ^e	300.3 ^f	109.0 ^f	89.4 ^g	3.126 ^e	3.049 ^f	0.280 ^e	0.273 ^f
6 (t ha ⁻¹)	4.907 ^d	3.247 ^g	12.95 ^c	12.63 ^d	318.9 ^{cd}	306.4 ^e	140.2 ^d	92.8 ^g	3.238 ^c	3.158 ^d	0.290 ^{cd}	0.279 ^e
8 (t ha ⁻¹)	5.907 ^b	4.600 ^e	13.28 ^b	12.87 ^c	339.8 ^b	315.4 ^d	168.8 ^b	131.4 ^e	3.319 ^b	3.217 ^c	0.309 ^b	0.287 ^d
10 (t ha ⁻¹)	6.410 ^a	5.600 ^c	14.29 ^a	12.95 ^c	365.2 ^a	321.3 ^c	183.1 ^a	160.0 ^c	3.572 ^a	3.237 ^c	0.332 ^a	0.292 ^c
LSD	0.145		0.120		4.219		4.129		0.030		0.004	
Means in the same column having different letters are significantly different using Fischer's protected LSD _(0.05) , CCM = Conventional chicken manure; LCM = Local chicken manure												

Table 6 Relationships between growth, yield, concentration and uptake of trace element by celosia grown on soil amended with chicken manure

	No of primary braches	No of leaf	Plant height	Root DMY	Shoot Cu- uptake	Shoot Cu	Shoot DMY	Shoot Mn- uptake	Shoot Mn	Total soil- Cd	Total soil- Cu	Total soil- Mn
			cm	g	mg plt ⁻¹	mg kg ⁻¹	g	mg plt ⁻¹	mg kg ⁻¹	mg kg ⁻¹		
No of primary braches	-											
No of leaf	0.97***	-										
Plant height	0.97***	0.96***	-									
Root DMY	0.68***	0.71***	0.75***	-								
Shoot Cu- uptake	0.72***	0.71***	0.78***	0.76***	-							
Shoot Cu	0.53***	0.52***	0.57***	0.64***	0.81***	-						
Shoot DMY	0.79***	0.76***	0.84***	0.75***	0.97***	0.67***	-					
Shoot Mn- uptake	0.76***	0.75***	0.82***	0.75***	0.96***	0.70***	0.97***	-				
Shoot Mn	0.70***	0.69***	0.73***	0.63***	0.76***	0.74***	0.74***	0.85***	-			
Total soil- Cd	0.65***	0.63***	0.68***	0.66***	0.82***	0.97***	0.72***	0.76***	0.82***	-		
Total soil- Cu	0.71***	0.68***	0.71***	0.64***	0.77***	0.89***	0.71***	0.71***	0.79***	0.91***	-	
Total soil- Mn	0.66***	0.63***	0.67***	0.65***	0.80***	0.93***	0.72***	0.73***	0.78***	0.94***	0.99***	-
*** significant at $p \leq 0.001$; DMY = Dry Matter Yield												

Table 7 Relationships between soil properties, metal transfer, uptake and bioaccumulation in tissues of celosia at 6 WAS

	pH	Org C.	ECEC	TF-Cu	TF-Mn	Root-Cu uptake	Root-Mn uptake	Shoot-Cu uptake	Shoot-Mn uptake	BAC-Cu	BAC-Mn	BCF-Cu	BCF-Mn
pH	-												
Org C.	-0.24 ^{ns}	-											
ECEC	0.56 ^{**}	-0.49 ^{**}	-										
TF-Cu	-0.79 ^{***}	0.13 ^{ns}	-0.55 ^{**}	-									
TF-Mn	-0.29 ^{ns}	0.85 ^{***}	-0.44 [*]	0.06 ^{ns}	-								
Root-Cu uptake	0.71 ^{***}	-0.28 ^{ns}	0.64 ^{***}	-0.65 ^{***}	-0.37 [*]	-							
Root-Mn uptake	0.74 ^{***}	-0.33 ^{ns}	0.58 ^{***}	-0.61 ^{***}	-0.45 [*]	0.98 ^{***}	-						
Shoot-Cu uptake	0.78 ^{***}	-0.31 ^{ns}	0.70 ^{***}	-0.62 ^{***}	-0.44 [*]	0.79 ^{***}	0.80 ^{***}	-					
Shoot-Mn uptake	0.86 ^{***}	-0.22 ^{ns}	0.59 ^{***}	-0.70 ^{***}	-0.30 ^{ns}	0.77 ^{***}	0.80 ^{***}	0.96 ^{***}	-				
BAC-Cu	0.38 [*]	-0.14 ^{ns}	0.75 ^{***}	-0.47 ^{**}	-0.22 ^{ns}	0.64 ^{***}	0.56 ^{**}	0.66 ^{***}	0.53 ^{**}	-			
BAC-Mn	0.81 ^{***}	-0.02 ^{ns}	0.35 ^{ns}	-0.71 ^{***}	0.06 ^{ns}	0.50 ^{**}	0.55 ^{**}	0.57 ^{**}	0.73 ^{***}	0.34 ^{ns}	-		
BCF-Cu	0.69 ^{***}	-0.13 ^{ns}	0.74 ^{***}	-0.86 ^{***}	-0.13 ^{ns}	0.74 ^{***}	0.67 ^{***}	0.74 ^{***}	0.72 ^{***}	0.85 ^{***}	0.62 ^{***}	-	
BCF-Mn	0.83 ^{***}	-0.50 ^{**}	0.52 ^{**}	-0.61 ^{***}	-0.53 ^{**}	0.64 ^{***}	0.73 ^{***}	0.73 ^{***}	0.79 ^{***}	0.43 [*]	0.81 ^{***}	0.60 ^{***}	-

***, **, * = Significant at $p \leq 0.001, 0.01, 0.05$, respectively; *ns* = not significant; WAS = weeks after sowing

Figures

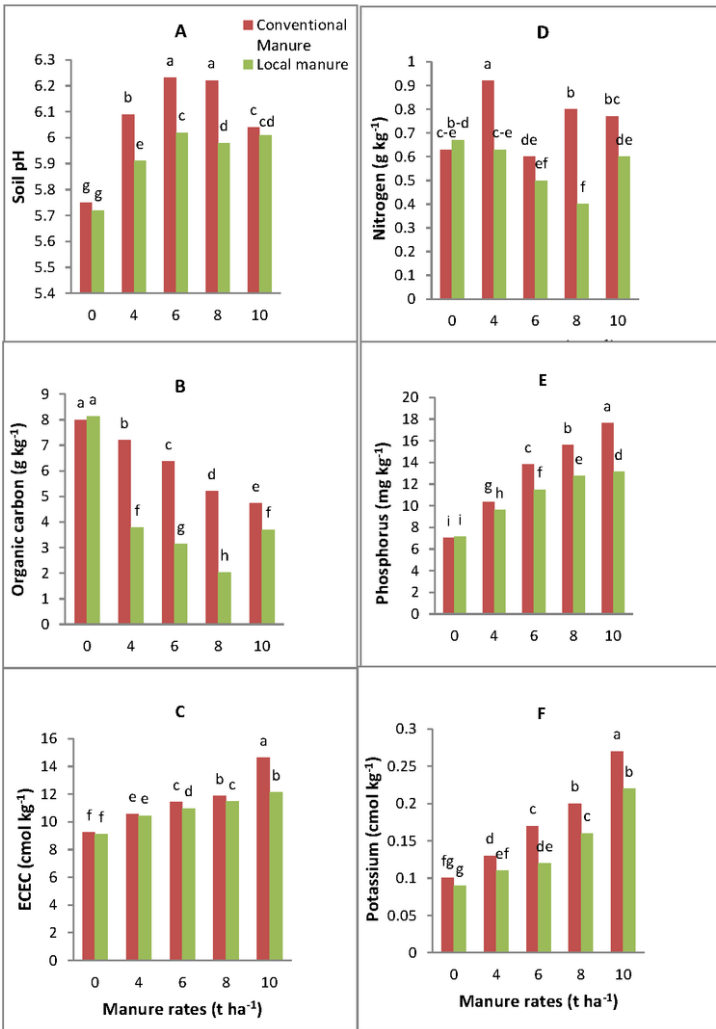


Figure 1

Effects of sources and rates of chicken manure amendments on soil chemical properties

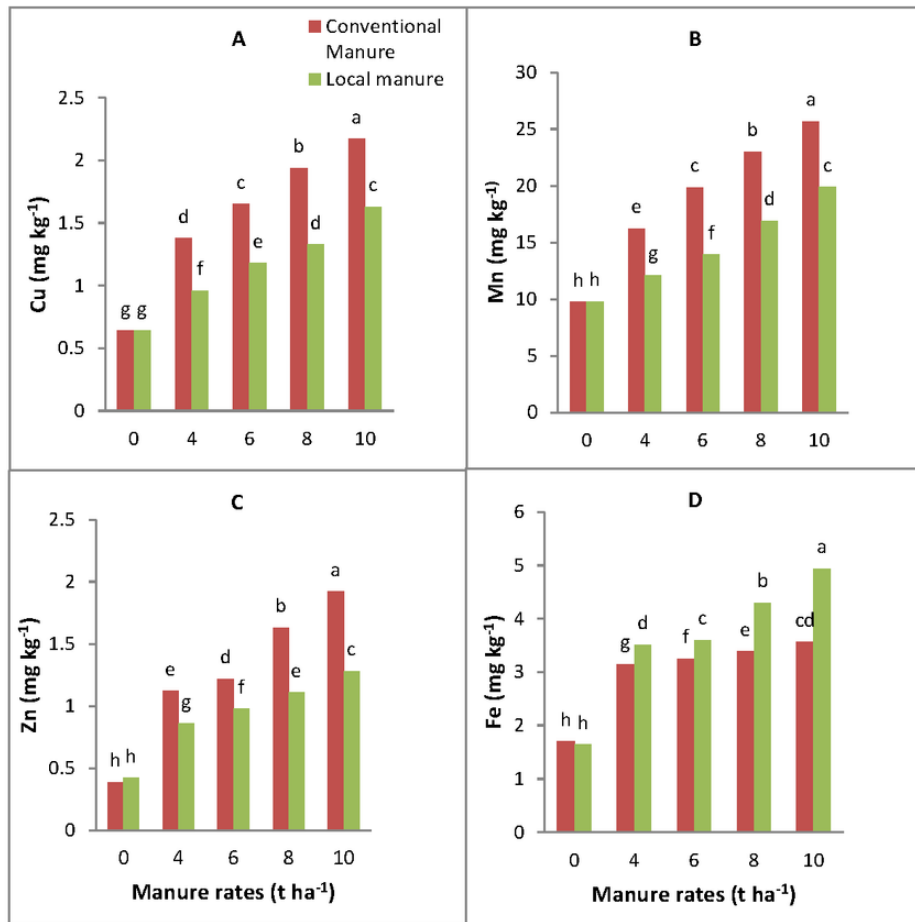


Figure 2

Effects of chicken manure sources and rates of amendments on soil trace element

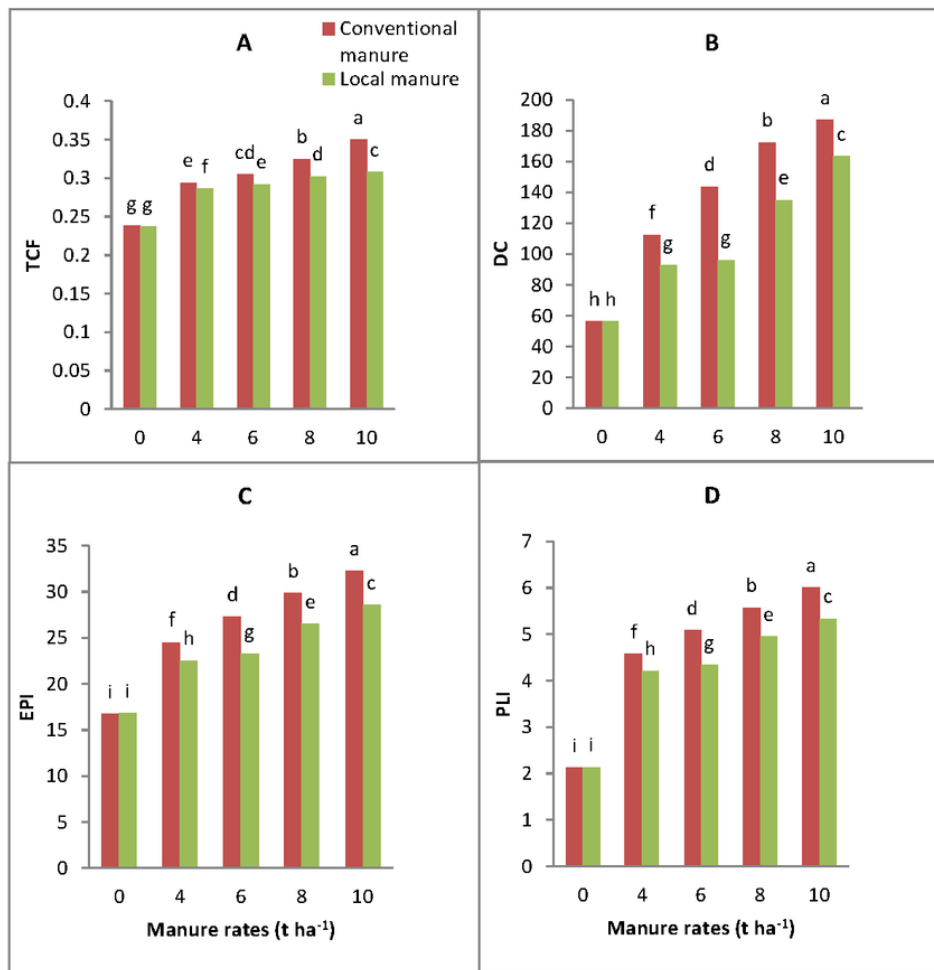


Figure 3

Pollution indices of Cd, Cu and Mn in soil amended with chicken manure

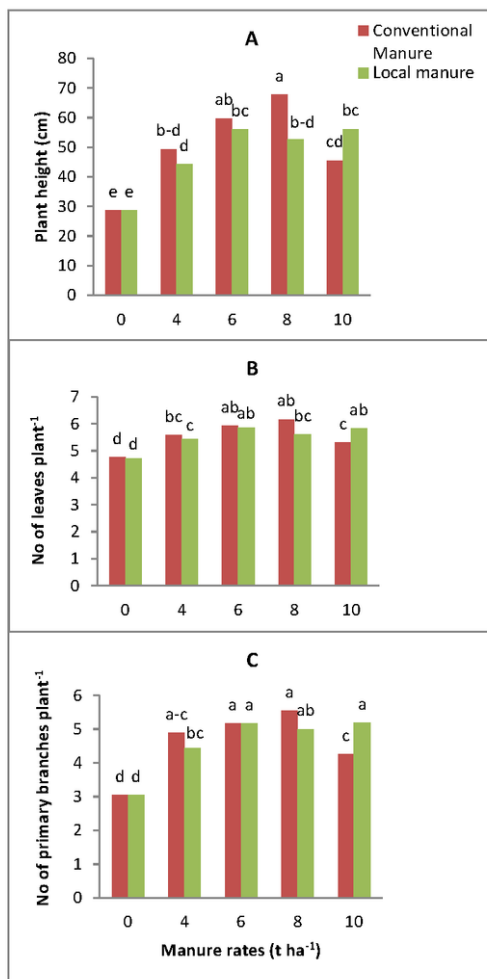


Figure 4

Effects of chicken manure amendments on growth of celosia at 6WAS

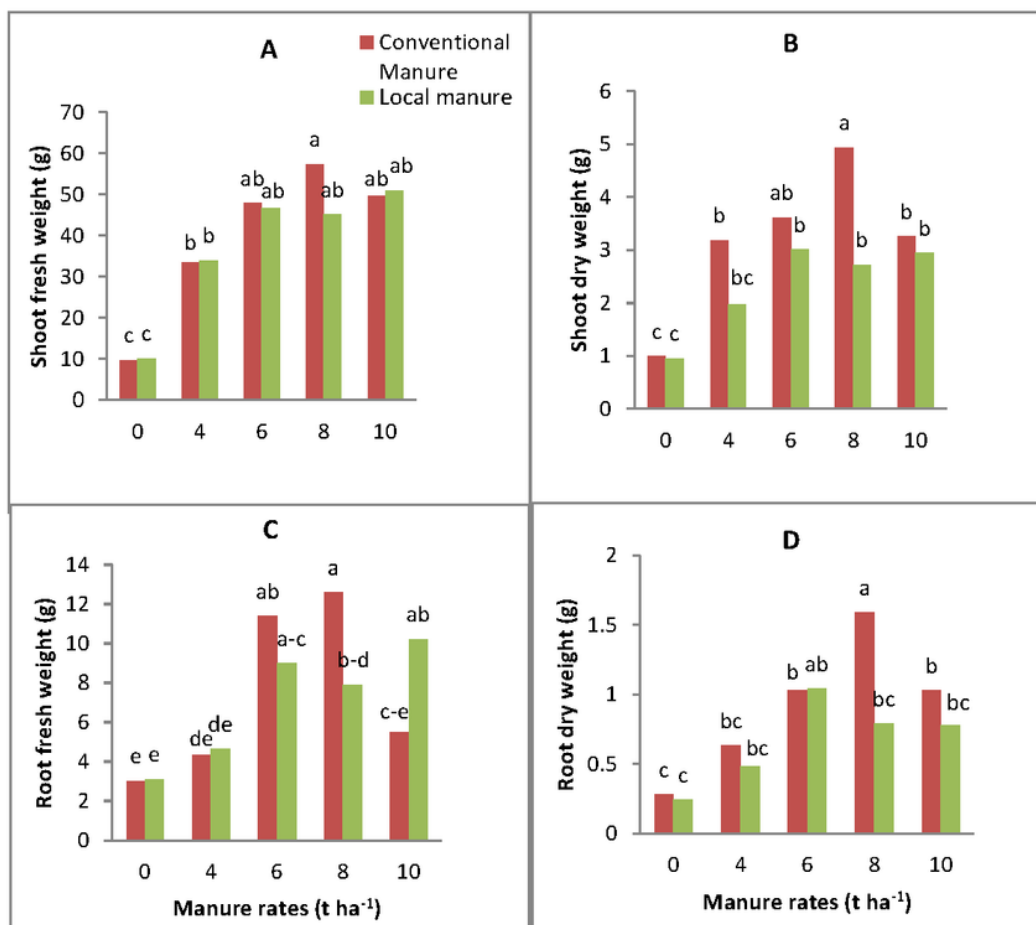


Figure 5

Effects of chicken manure amendments on yield of celosia at 6 WAS

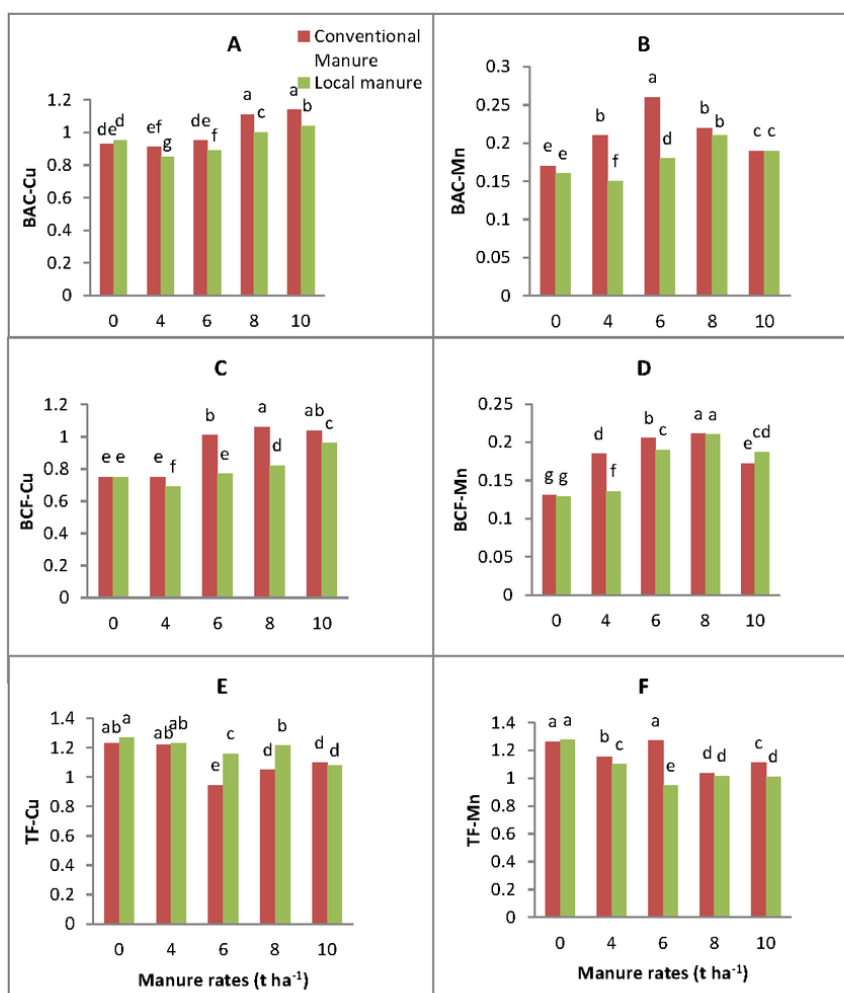


Figure 6

Bioaccumulation of trace element in *Celosia argentea* grown on soil amended with chicken manure

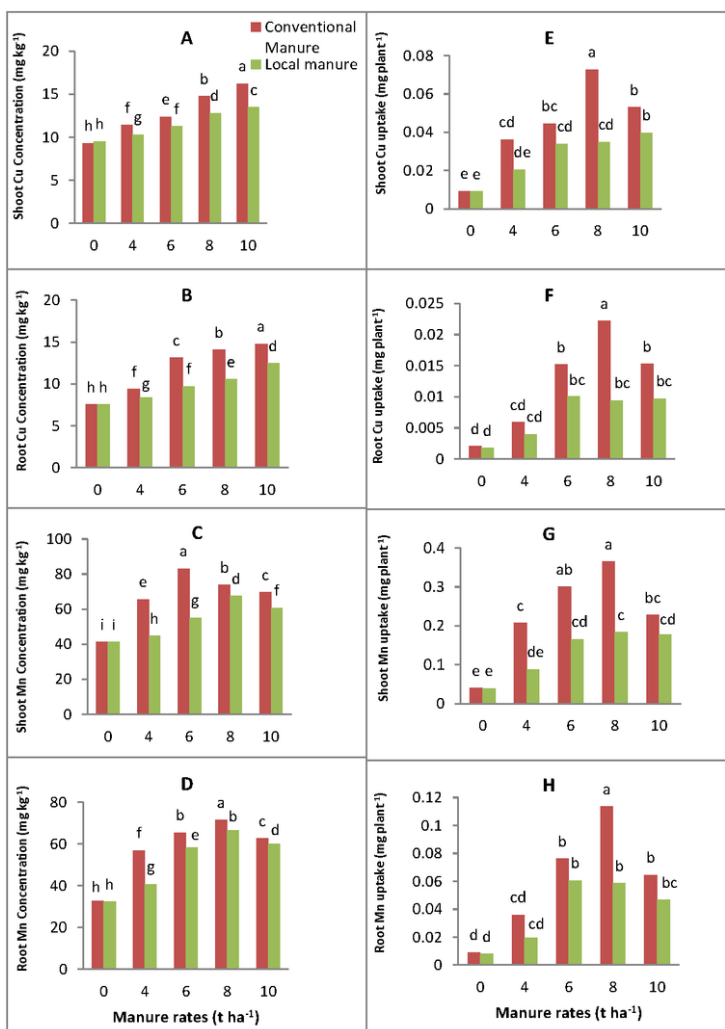


Figure 7
Concentrations and uptake of Cu and Mn by root and shoot tissues of *Celosia argentea* grown on soil amended with chicken manure

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [SupplementaryTable.docx](#)