

Heavy metals concentrations and risk assessment of roselle and jute mallow cultivated with three compost types



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ABSTRACT

Field experiments were conducted at the research field of the CSIR–SARI near Nyankpala in the Northern region of Ghana during the major growing seasons of 2014 and 2015. The objectives of the study were to determine the effect of three compost types i.e. Accra compost and recycling plant (ACARP) compost; decentralised compost (DeCo) and composted deep litter chicken manure (CDLCM) on heavy metals concentrations in roselle (*Hibiscus sabdariffa* L.) and jute mallow (*Corchorus olitorius* L.) and the health risk of these vegetables to adults and children. The composts were each applied at the rate of 10 t/ha in a randomized complete block design in four replications. The concentrations of Cd and Pb in the leaves of roselle were 0.8 mg/kg and 5.0 mg/kg while in jute mallow, they were 0.7 mg/kg and 6.0 mg/kg, respectively. These concentrations were above the Maximum residue levels (MRLs) of 0.2 mg/kg for Cd and 0.3 mg/kg for Pb in the standards of the European Commission and Codex Alimentarius Commission. The low soil pH might have facilitated the bioavailability of the heavy metals resulting in concentrations that could be harmful to consumers of these vegetables. There is, therefore, the need to amend the soil pH of the study area. An upward adjustment of the pH of the composts used can also help in reducing the bioavailability of heavy metals to roselle and jute mallow cultivated in soils with low pH.

Introduction

Heavy metals are inherent in soils as part of the weathering processes in soil formation at trace levels that are rarely toxic (Kabata-Pendias, 2011). Their concentrations in soils and other growing media are, however, increased by the application of certain types of inorganic and organic fertilisers which contain heavy metals that are bioavailable to plants (Chaney, 2012). Delgado Arroyo et al. (2014) reported that poultry manure, apart from the nutrients it contains for plant growth, also contain heavy metals including Pb, Cd, Zn, Cu and Ni. In a related study, Ghaly and Alkoaik (2010) found that the organic fraction of municipal solid waste contained 1.1 mg/kg Zn and as much as 211.0 mg/kg Cu. Similarly, a report by Ayari et al. (2010) indicated that municipal solid waste compost contained 337 mg/kg Cu, 1174.5 mg/kg Zn, 411.5 mg/kg Pb and 5.17 mg/kg Cd. As far as plants are concerned, Pinamonti et al. (1997) observed that application of compost in an orchard, resulted in increase in Pb and Cd concentration in the leaves and fruits of apple.

Vehicular emissions also contribute heavy metals to the environment. This is evident in a report by Popescu (2011) which indicated

that emissions from vehicles release heavy metals such as lead and cadmium into the atmosphere which are washed into the soil through rain. Plants absorb these heavy metals into their edible parts which are in turn consumed by humans.

The uptake of heavy metals, their mobilization into plant tissues, and storage in the aerial plant biomass is referred to as Bio-concentration factor (BFC) which is considered the most important plant feature in phytoremediation. It is a ratio of heavy metal concentration in plant shoot to extractable concentration of heavy metal in the soil (Oti, 2015). Vegetables especially, the leafy ones are known to be high accumulators of these heavy metals and because they are consumed more frequently, poses a high risk to humans. For example, Wamalwa et al. (2015) tested some leafy vegetables in an urban community for heavy metals and found that Pb levels were above accepted maximum residue levels (MRLs).

The consumption of heavy metal-contaminated vegetables results in the accumulation of these heavy metals in vital organs of the human body leading to chronic health problems such as liver and kidney damage (Martin and Griswold, 2009; Karman et al., 2013). The risk associated with the consumption of these vegetables is determined using

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the hazard quotient (HQ). The HQ is a ratio of the average daily dose of the heavy metal to a reference dose (Hough et al., 2004). If HQ is greater than one (1), there is a potential risk to the consumer but if it is less than one, there is no potential risk to the consumer. The sum of the HQs of individual heavy metals through a single exposure pathway constitute the hazard index (HI) (Hu et al., 2013; Sharma et al., 2016).

The objectives of this study were to determine the effect of some selected composts on the bioavailability of Cd, Pb, Zn and Cu in the harvested leaves of roselle and jute mallow and also to assess the health risk associated with their consumption within the area.

Materials and methods

The study area

The study was conducted at the upland field of the Council for Scientific and Industrial Research – Savanna Agricultural Research Institute (CSIR-SARI), Nyakpala, located in the Tolon District of the Northern Region of Ghana. The upland field is about 200 m from Changnaayili village (Latitude 09 25/N, Longitude 00 58/W, and altitude of 183 m above sea level). The soils of the upland field are *Ferric luvisols* (FAO-UNESCO, 2002), reported to have derived from concretionary ground water laterite soil described as Kpalsawgu series (imperfectly drained, occurring within the east on the low lying uplands) and Changnayili series (poorly drained, occupying the lower slopes and valley bottoms) which are both sandy loam soils that are slightly acidic with pH of 5.8 (Obeng, 2000). The experiment was conducted on the Kpalsawgu soil series. The experimental site has been cultivated to a variety of crops including cereals, legumes and vegetables under different experimental treatments.

The study area has two distinct seasons (rainy/wet season and dry season). The rainy season is mono-modal which begins around May and ends around October. The amount of rainfall recorded annually varies between 750 mm and 1050 mm with a cropping period of 180–200 days (MoFA, 2013). The dry season starts around November and ends around March/April with maximum temperatures (°C) occurring around March-April and minimum temperatures (°C) around December/January. The harmattan (north-east trade winds) occurs around December to early February and has a considerably low temperature effect in the region; normally 14 °C at night and 40 °C during the day. Relative humidity, however, which is very low during harmattan, mitigates the effect of the daytime temperature. The vegetation mostly consists of vast areas of grassland, interspersed with guinea savannah woodland, characterised by drought-resistant trees such as acacia, baobab, shea nut, dawadawa, mango, and neem.

Source of seeds and composts

Seeds of local cultivars of roselle and jute mallow were obtained from farmers at Builpela and Gbulahgu irrigation sites in the Tamale metropolitan area and Tolon district, respectively. Samples of ACARP compost was obtained from a sales agent in Tamale while the DeCo compost and the CDLCM were obtained from the DeCo Company near Tamale.

Land preparation and application of compost

The experimental field was mechanically ploughed and harrowed to a fine tilth. A total area of 20 m × 15 m was then lined and pegged to carve out the experimental plots. The organic soil amendments were incorporated into the top 10–15 cm of the soil using a hand hoe. The composts were spread by hand gently on each plot at a rate of 10 t/ha and worked into the top soil using the hoe. This was done two weeks before transplanting was done. The seeds of roselle and jute mallow were nursed in nursery boxes. The seedlings at 31 days in the nursery were transplanted onto the field at 40 × 40 cm spacing. Each

experimental plot had a plant population of twenty five. Harvesting was done on the nine inner plants when the leaf cover was considered economical at each point in time of the plant's growth for further processing and analysis.

Experimental design and field layout

The treatments were ACARP, DeCo, CDLCM and control (which was without any amendment). The experiment was laid out in a randomized complete block design with four replications.

Determination of chemical properties and heavy metals (Cu, Zn, Cd, and Pb) concentrations in soil and composts

Sample preparation and analysis were conducted in reference to the handbook of methods on tropical soil biology and fertility by Anderson and Ingram (1993). Ten soil samples were randomly taken from the experimental plot at 15 cm depth at 9:00 am GMT using a soil auger. They were dried in an oven at 104 °C for 24 h. They were then pulverised into finer particles, sieved, mixed thoroughly and composited. Three laboratory samples were then taken from the composite sample for analysis. The soil and the composts were analysed for their compositions of percent nitrogen by the Kjeldahl method; percent organic carbon by Wakley and Black method; elemental phosphorous using the UV-Vis (model 7305, Bibby Scientific, Staffordshire, UK); potassium using the flame photometer (model PFP7, Bibby Scientific, Staffordshire, UK) and pH using the research pH meter (model 3330, Jenway Ltd., Essex, UK) by following standard procedures. The extraction of the heavy metals in the soil as well as the composts was done using Ethylenediamine tetracetic acid (EDTA) with ammonium acetate as a universal extractant. The heavy metals were then determined using the Atomic Absorption Spectrophotometer (AAS) at the Analytical Laboratory of the Soil Research Institute at Kwadaso in Kumasi.

Determination of chemical properties and heavy metals (Cu, Zn, Cd, and Pb) concentrations in roselle and jute mallow leaves

For the leaves, 0.5 g of the dried samples were then weighed into crucibles and placed in a muffle furnace at a temperature of 450 °C for 3 h. The samples were allowed to cool and 10 ml of 1:2 dilute Nitric acid solution was added to each sample. They were placed on a hot plate until the first sign of boiling was observed. The samples were then filtered into a 20 ml flask and made to the mark with distilled water. One ml of the solution was then injected into the AAS flow injection tube for determination of the heavy metals (Motsara and Roy, 2008). The concentrations of the heavy metals were determined using the AAS (model 210 VGP, Buck Scientific, East Norwalk, USA). The concentration of the heavy metals was then calculated as follows: Heavy metal concentration (mg/kg) = C × df. Where C – concentration of heavy metal from AAS reading and df – dilution factor.

The bio-concentration factor (BCF) for the various metals was determined by dividing the concentration of each metal in the dry leaves of roselle and jute mallow by the concentration of the metal in the soil. The health risks of the heavy metals were also determined by calculating their hazard quotients (HQ) according Sharma et al. (2016) as follows:

$$HQ = ADD/RfD = C \times EF \times ED/BW \times AT \times RfD$$

where

HQ = Hazard quotient (unitless)

ADD = Average daily dose (mg/kg-day).

RfD = Reference dose (mg/kg-day).

C = (mg/kg fresh weight basis) is the measured concentration of heavy metals on individual heavy metal basis in the edible part of the vegetable.

IR = (kg/day per person) is the amount of daily vegetable consumption.

NB: The average IR in Ghana is 0.137 kg/day per person (Ruel et al., 2005).

EF = (350 days/year) is the exposure frequency to a particular heavy metal.

ED = the exposure duration (6 years for child, 30 years for adult).

BW = the body weight (24.5 kg for child, 60.3 kg for adult).

AAT = the average life time for non-carcinogens (ED-365 days/year).

The risk analysis (HQ) was done separately for an adult (body weight of 60 kg) with an exposure duration of 30 years and a child (body weight of 24.7 kg) with an exposure duration of 6 years.

Statistical analysis

Data collected were subjected to analysis of variance (ANOVA) using GenStat release 9.2 statistical package. Fisher's least significant difference (LSD) test was used to separate the treatment means at 5% level of significance.

Results and discussion

Concentration of heavy metals (Cu, Zn, Cd and Pb) and other chemical constituents in the soil, CDLCM, ACARP and DeCo composts

The experimental soil was analysed for the concentrations of Cd, Pb, Zn, Cu, N, P, K and C, and the pH level determined before the amendments were applied. The results are presented in Table 1. The pH of the soil indicated an acidic condition (4.4) with organic carbon at 2.0% and nitrogen content at 0.2%. The potassium content in the soil was 261.3 mg/kg while phosphorous was 38.7 mg/kg. Zinc concentration was 17.6 mg/kg and Copper was 6.5 mg/kg. The concentrations of the two non-essential heavy metals (Pb and Cd) were 5.5 mg/kg and 0.5 mg/kg, respectively. All the composts were also acidic with the lowest average pH of 3.9 in CDLCM and highest of 4.8 in DeCo. The nitrogen contents in the composts were 0.3% in both ACARP and DeCo but 0.6% in CDLCM while the least carbon content was 1.6% in ACARP and highest in CDLCM (7.5%). On average, ACARP contained the highest of all the metals followed by DeCo and then the CDLCM (Table 1).

In this study, the concentration of the two essential heavy metals - Cu and Zn in the soil were considered normal for plant growth. According Schulte and Kelling (1999), the soil Cu concentration ranges from 2 mg/kg to 100 mg/kg. The crop however removes less than 0.05 mg/kg per year. The concentrations found in this study were similar to those reported by Antonio and John (2013) and by Pariera and Clain (2013). Other authors, however, reported much higher soil Cu concentrations of 50 mg/kg (ATSDR, 2004); 1,300–1400 mg/kg

Table 1

Concentrations of heavy metals (Cu, Zn, Cd and Pb) and other chemical constituents in CDLCM, ACARP compost, DeCo compost and the soil (n = 3).

| Chemical constituents | CDLCM | ACARP compost | DeCo compost | Soil |
|-----------------------|-------|---------------|--------------|-------|
| pH | 3.9 | 4.3 | 4.8 | 4.4 |
| C (%) | 7.5 | 1.6 | 3.6 | 2.0 |
| N (%) | 0.6 | 0.3 | 0.3 | 0.2 |
| P (mg/kg) | 72.3 | 59.6 | 79.1 | 38.7 |
| K (mg/kg) | 446.9 | 368.6 | 494.4 | 261.3 |
| Zn(mg/kg) | 3.2 | 19.5 | 1.8 | 17.6 |
| Cd (mg/kg) | 0.1 | 3.4 | 0.5 | 0.5 |
| Pb (mg/kg) | 0.7 | 4.2 | 1.6 | 5.5 |
| Cu (mg/kg) | 1.1 | 6.8 | 2.8 | 6.5 |

The values represent means of three replicates on dry matter basis.

Table 2

Effect of different organic soil amendments on heavy metal concentration in harvested leaf samples of roselle (n = 4).

| Soil amendment | Zn (mg/kg) | Cu (mg/kg) | Cd (mg/kg) | Pb (mg/kg) |
|----------------|------------|------------|------------|------------|
| ACARP | 18.8 | 12.5 | 0.6 | 4.1 |
| DeCo | 31.5 | 11.5 | 1.1 | 5.9 |
| CDLCM | 18.6 | 11.4 | 0.9 | 4.9 |
| Control | 22.3 | 12.5 | 0.6 | 3.6 |
| LSD (5%) | 12.1 | 5.4 | 1.2 | 3.4 |

The values are means of four replicates expressed on dry weight basis.

Table 3

Effect of different organic soil amendments on heavy metal concentration in harvested leaf samples of jute mallow (n = 4).

| Organic soil amendment | Zn (mg/kg) | Cu (mg/kg) | Cd (mg/kg) | Pb (mg/kg) |
|------------------------|------------|------------|------------|------------|
| ACARP | 26.5 | 17.6 | 0.6 | 6.7 |
| DeCo | 22.8 | 16.3 | 1.0 | 5.2 |
| CDLCM | 16.6 | 15.3 | 0.4 | 5.4 |
| Control | 16.7 | 15.9 | 0.9 | 5.9 |
| LSD (5%) | 9.1 | 2.8 | NS | NS |

The values are means of four replicates expressed on dry weight basis.

Table 4

Effect of different organic soil amendments on Bio-Concentration Factors (BCF) in roselle and jute mallow leaves (n = 3).

| Heavy metal type | BCF - roselle | BCF - jute mallow |
|------------------|---------------|-------------------|
| Cd | 1.60 | 1.45 |
| Zn | 1.30 | 1.17 |
| Pb | 0.84 | 1.05 |
| Cu | 1.84 | 2.50 |

Values are means of three replicates expressed on dry matter basis.

(Nachtigall et al., 2007) and 1197.6 mg/kg (Suciu et al., 2008). Alloway (2008) reported a mean concentration of 55 mg/kg for Zn in soils from different geographical locations. A report jointly submitted by IFPRI, IFDC, ILFSP, MSU and IITA (2015) to the Ministry of Food and Agriculture in Ghana, showed the following fertility status of the Guinea Savanna soils - pH, 6.2–6.6; organic carbon, 0.51–0.99%; total N, 0.02–0.12%, available P and K 0.06–1.80 and 36.96–44.51 mg/kg respectively. In this study, however, the P and K were relatively high while the pH was comparatively low.

The concentrations of Cd (0.5 mg/kg) and Pb (5.5 mg/kg) in the experimental soil were similar to concentrations reported by WHO (2007) and by Biernacka and Maluszynski (2006) as typical values for most soils. Chaney (2012) and Tchounwou et al. (2014) reported that the normal cadmium concentration in agricultural soils ranges from 0.1 to 2 mg/kg. The Pb concentration in experimental soil was however, below the 10–50 mg/kg threshold reported by ATSDR (2012) and 1521.8 mg/kg by Suciu et al. (2008). Therefore, the concentrations of the two non-essential heavy metals in the experimental soil were within acceptable levels for crop cultivation.

The presence of Pb, Cd, Cu and Zn in CDLCM used in this experiment corroborated with studies by Delgado Arroyo et al. (2014) and Chastain et al. (1999) where Pb, Cd, Cu and Zn were found in poultry manure. Similarly, Irshad et al. (2013) also reported 28 mg/kg Pb and 48 mg/kg Cd in chicken manure. The two municipal solid waste composts, ACARP and DeCo also contained Cd, Pb, Cu and Zn which can be related to a similar study by Ayari et al. (2010), where they found that municipal solid waste compost contained 337 mg/kg of Cu, 1174.5 mg/kg of Zn, 411.5 mg/kg of Pb and 5.17 mg/kg of Cd. From the concentrations of the heavy metals, ACARP could be graded as B (suitable for land reclamation) while DeCo and CDLCM be graded as A+ (suitable for agriculture including organic farming) according to the

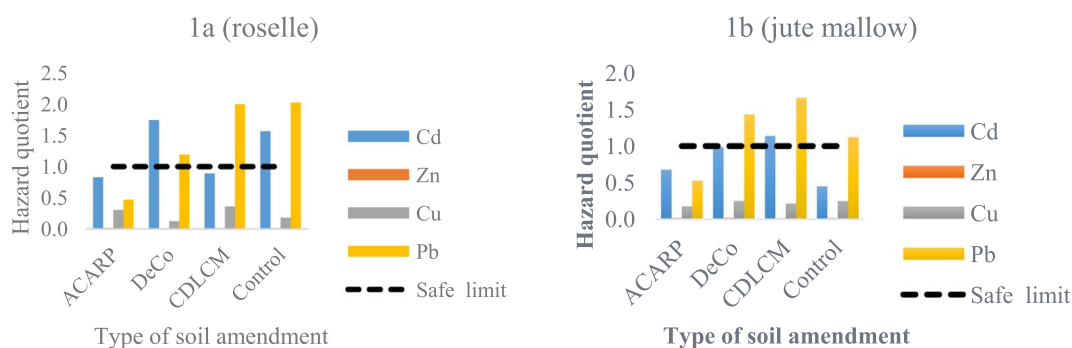


Fig. 1. (a and b) Health risk assessment of heavy metals in roselle and jute mallow leaves respectively (n = 4) for adults.

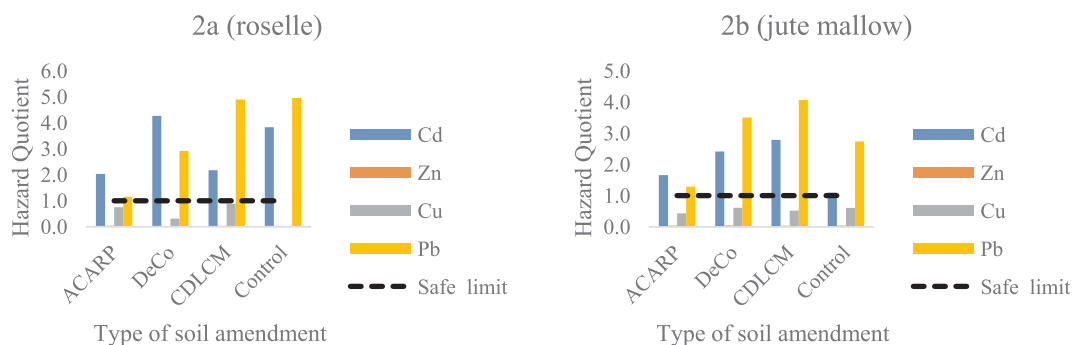


Fig. 2. (a and b) Health risk assessment of heavy metals in roselle and jute mallow leaves respectively (n = 4) for children.

European Commission (2004) standards on the heavy metal concentration in compost for agricultural use.

Heavy metal concentration in harvested leaves of roselle and jute mallow

The leaf samples of roselle (Table 2) and jute mallow (Table 3) contained all the heavy metals analysed for viz Zn, Cu, Cd and Pb as residues. The roselle produced from the DeCo compost-amended plots had the highest concentration of Zn (31.5 mg/kg) in the leaves. This was significantly different ($P \leq 0.05$) from ACARP and CDLCM but not significantly different from the control plots. For Cu, Cd and Pb, there was no significant differences in their concentration for all the amendments. In the leaves of jute mallow, the concentration of Zn from the ACARP – amended plots was 26.5 mg/kg and this was significantly different from the CDLCM (16.6 mg/kg) and the control (16.7 mg/kg) plots. However, the concentrations of Cu, Pb and Cd in the leaves were not significantly different for all the amended plots.

The results of the plant analysis showed that the concentrations of the two carcinogenic heavy metals – Cd and Pb in this study were both above the maximum residue levels (MRLs). Though the concentration of Cd in both roselle and jute mallow were not significantly different among the various amendments, they were above the 0.2 mg/kg maximum residue level (MRL) for leafy vegetables as set by Codex Alimentarius Commission (FAO/WHO, 2011) and European Commission (EC, 2006).

The concentrations of Pb in roselle and jute mallow leaves in all the treatments were above the MRLs of 0.3 mg/kg for vegetables, as in the Codex Alimentarius Commission and EC standards.

The higher concentrations of Cd and Pb in these vegetables, with or without the application of compost, could be attributed to the low soil pH which enhanced the uptake of these metals from the soil. Based on this, Traunfeld and Clement (2001) indicated that adjusting the pH of garden soils to 6.5–7.0 reduces the bioavailability of Pb in the soil for plants uptake. In a similar study, Wamalwa et al. (2015) also found Pb levels in some leafy vegetables to be above the Codex MRLs. According to Tangahu et al. (2011), Pb is immobile in the soil but its uptake varies

within genotypes and even within the same plant species. According to Jung (2008) and Nouri et al. (2009), several factors including movement of water within the field, interaction among the elements and variations in uptake in the plant contribute to varying concentrations of heavy metals in plants.

Bio-Concentration Factors (BCF) of roselle and jute mallow leaves

In this experiment, BCF was calculated by dividing the concentration of each heavy metal in roselle and jute mallow by the concentration of the heavy metal in the soil. The values obtained were in the decreasing order of $Cu > Cd > Zn > Pb$ for both roselle and jute mallow (Table 4). This indicated that Cu was the most accumulated heavy metal while Pb was the least accumulated in the leave of roselle and jute mallow. Roselle had the highest concentrations of Cd and Zn but less of Pb and Cu compared with jute mallow. Considering the two carcinogenic elements (Cd and Pb), the Cd uptake and translocation being higher than Pb is similar to findings by Ndeda and Manohar (2014) and Hladun et al. (2015).

Health risk assessment of heavy metals in roselle and jute mallow leaves for adults and children

The hazard quotient (HQ) for Zn and Cu in both roselle and jute mallow were below 1.0 for all the amendments including the control. This implied that the concentrations of these two heavy metals in the leaves of the vegetables did not pose any health risk to both adults (Fig. 1a and b) and children (Fig. 2a and b). However, the HQ for Pb and Cd on average posed a health threat to both children and adult populations. The risk was more pronounced in roselle than in jute mallow for the adult population but not as in children.

This study showed that, children were at a higher risk compared to their adult counterparts. Though both vegetables posed health risk as shown by their HQs, roselle had a higher HQ compared to jute mallow for both adults and children. Roselle therefore, poses more health risk than jute mallow for the two category of consumers over time. In a

report by SCOOP (2004), it was indicated that though food intake of children is lower than that of adults, their lower body weight predisposes them to higher risk.

For both adults and children, roselle had a higher HQ than jute mallow, a similar trend observed with Cd. In a related study, Jena et al. (2012) estimated HQ for Pb to be 7.22 in leafy vegetables. Zhou et al. (2016) also found the target HQ for Pb to be 1.15, 1.51 and Cd to be 2.49, 3.27 in vegetables for adults and children respectively. Considering its relative uptake for different age groups, the WHO (2010) indicated that gastrointestinal absorption of lead is enhanced in children and thus up to 50% of ingested lead occur in children, as compared with 10% in adults. Apart from the health risk of Cd and Pb being higher for children, the higher HQs associated with roselle suggested that consumers were exposed to higher risk in consuming roselle than jute mallow.

Conclusion

The results of the study revealed that the three composts, ACARP, DeCo and the CDLCM contained acceptable levels of cadmium, lead, zinc and copper for agricultural production. These amendments, however, had low pH values and their application to soils with low pH will enhance the uptake of heavy metals by vegetables such as roselle and jute mallow leading to concentrations above international standards. In order to reduce the uptake of metals and ensure the safety of roselle and jute mallow produced for consumption, there is the need for farmers to adopt strategies to increase the pH of the soil in the study area.

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