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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 whiles 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 nursey 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.